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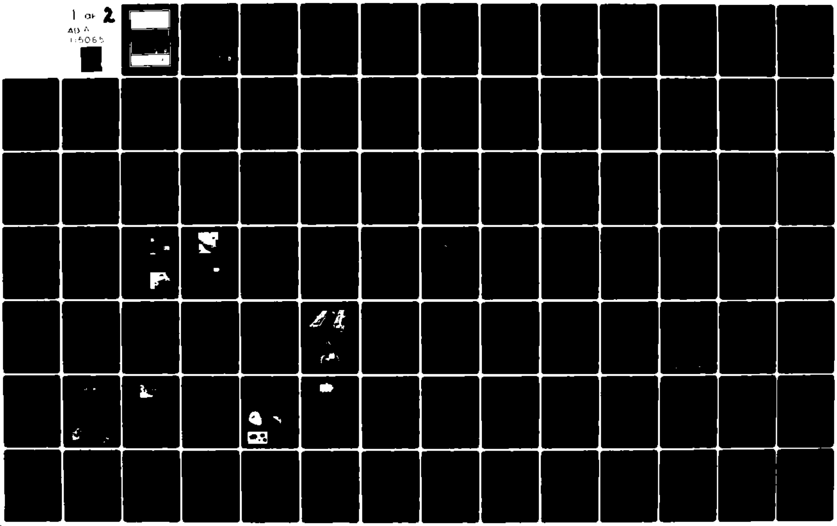

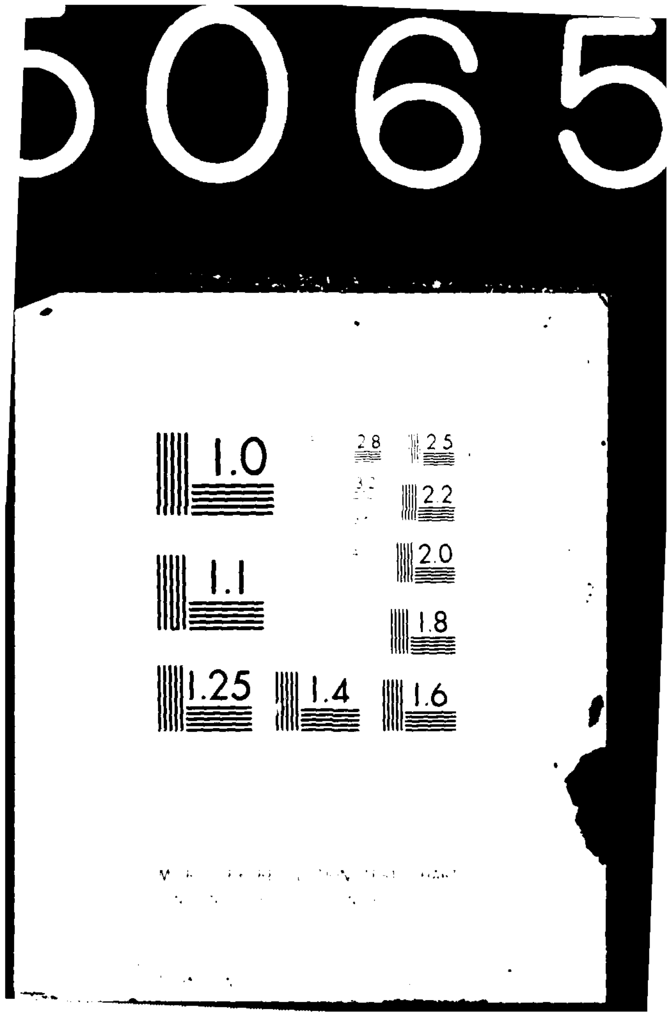
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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Impact of Advanced Avionics Technology on Ground Attack Weapon Systems

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.306

IMPACT OF ADVANCED AVIONICS TECHNOLOGY ON GROUND ATTACK WEAPON SYSTEMS

Copies of papers presented at a Meeting of the Avionics Panel held in Agheos-Andreas, Greece, 19–23 October 1981.

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THEME

In the event of a conflict, the main concerns of NATO will be to overcome heavy enemy armor thrusts, to disorganize enemy command and control centers, to destroy their storage depots, and to make their airfields unserviceable. Air-to-ground tactical operations will have a high degree of priority and will be conducted by day, night, and in adverse weather. The solution to these mission requirements will comprise a number of interdependent operational segments involving a wide range of advanced technologies; the present symposium will concentrate upon the ground attack aircraft and its weapons. Tactical aircraft involved in air-to-ground missions will fly at very low altitude over enemy territory to avoid counter air-defenses, and will operate in severe jamming conditions. For this reason, an autonomous capability to detect and attack the targets will be highly desirable. In addition, several tasks will have to be performed simultaneously viz: navigation, flight at low altitude, target detection, recognition and fire control. The choice between twin and single seat aircraft to accomplish the mission is still controversial. The single seat aircraft will require a high degree of automation to alleviate pilot workload.

In the past decade it has been impossible to assign such complex tasks to single seat or even twin-seat tactical aircraft. Autonomous operations conducted by day, night, and in adverse weather are associated with a high degree of automation, requiring sensors with high performance and a large data and signal processing capacity. These lead to Avionics packages of which the weight, volume and power consumptions have tended to preclude their introduction into tactical aircraft of moderate size.

The vulnerability of attack aircraft to the ground to air defenses and the excessive workload of the pilot in the guidance of air-to-ground weapons are pointing to the concept of a generation of fire-and-forget weapons. New technology can be expected to allow weapons with extended ranges and improved performance in both good and adverse weather when compared with existing installations.

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The Panel wishes to express its thanks to the Greek National Delegates for the invitation to hold this Meeting at Agheos-Andreas and for making available the facilities and personnel which made the Meeting possible.

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IMPACT OF ADVANCED AVIONICS AND MUNITIONS TECHNOLOGY

ON

GROUND ATTACK WEAPONS SYSTEMS IN NIGHT AND ADVERSE WEATHER CONDITIONS

By

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SUMMARY

This paper provides an overview on avionics technology and munitions developments which will provide additional capability for NATO forces to operate at night and in adverse weather conditions.

INTRODUCTION

It is a distinct pleasure to be included in such a distinguished group of international experts gathered to discuss requirements and plans for air operations at night and in adverse weather. Forums such as this perform a great service to NATO by bringing together and concentrating the attention of both NATO government and industry personnel on the challenges associated with conducting military operations. Working together, we can improve our ability to develop and deploy affordable solutions to our defense needs.

My presentation has drawn heavily from material prepared by Brigadier General C. D. Smith, USAF, presently the USAF Deputy Director for Strategic Mobility assigned to the Joint Chiefs of Staff. In his previous assignment, he was responsible for U.S. Air Force requirements. He presented his views on this subject to the American Defense Preparedness Association (ADPA) on 11 February 1981 in Orlando, Florida.

ENVIRONMENTAL CONDITIONS OUR FORCES MAY ENCOUNTER

I would like to begin by showing a few viewgraphs which provide the basis for describing the magnitude of conducting operations during periods of darkness and adverse weather. They will help to quantify the problems many of us will be addressing here this week.

The first chart shows the operating window or the environmental conditions of combat that our forces may encounter worldwide. The three areas selected were Europe, the Arabian Gulf and Korea. The worst weather month in each of these areas was also selected to illustrate the conditions historical data indicate will exist during a typical 24-hour day. As many of you in the audience can confirm from first-hand experience, Central Europe provides the most hours of nonvisual conditions. It presents us with the most difficult challenge, over nineteen hours of darkness and adverse weather during the average 24-hour period during a typical January.

Now to look at those conditions in central Europe in another way. We have divided the operating window to show how it will exist during both the summer and winter. Even in the summer, night and adverse weather conditions are expected nearly one half of the time. The conditions shown on the previous chart, for the month of January, also exist throughout the entire winter.

THE CAPABILITY OF OUR POTENTIAL ADVERSARIES

As vivid as these statistics point out, we need forces that can operate at night and in adverse weather. Environmental conditions are only part of the problem. The other part of the problem, and perhaps a more important part, is the capability of our potential adversaries; the threat our forces may encounter during poor environmental conditions. The potential threat is large today and growing even larger. It is also growing in sophistication, highly capable, and increasing in capability. For example, during the past decade, the Soviet Union and the Warsaw Pact have been aggressively developing, producing, and deploying large numbers of tactical aircraft with increasingly improved avionics and weapons. During this period, they have produced tactical aircraft, on the average, at twice the rate that we do and are now producing a new aircraft every seven hours for a total of over 1200 per year. If we were to produce and deploy aircraft at this same rate, we could reequip the United States Air Force in Europe every seven months or the entire active tactical fighter inventory every eighteen months.

As impressive as these Soviet quantitative advancements are, equally disconcerting are the significant qualitative improvements achieved during this period. The Soviets have moved away from the generally short-ranged, defensive aircraft which characterized their frontal aviation forces in the 1950s and 60s. Improvements made in the Fishbed, Flogger, Fencer and Foxbat provide them a force which has greatly improved radius of action with more sophisticated avionics and weapons. They are expected to field advanced air superiority fighters by the mid-80s with energy maneuverability comparable to the F-16. The Soviets are also upgrading the air-to-air radar and missile capabilities of their fighters. Early in this decade, they may deploy a new aircraft with lookdown/shootdown capability. These developments could dramatically increase the threat to our offensive forces operating at low altitude.

Improvements in Soviet surface-to-air defensive capabilities pose additional threats to our tactical aircraft. New Soviet systems possess increased mobility and greater rate of fire, giving them improved capability against our low level penetrators.

Soviet doctrine demands that their ground and air forces be able to operate twenty-four hours a day, in all weather conditions. The Soviets have recognized that unique opportunities for success exist for those forces operating at night and in adverse weather. They realize that it is during periods of darkness and adverse weather that their opposition's effectiveness is reduced with his defenses degraded. Large numbers of aircraft will be on the ground being rearmed and repaired and potentially more vulnerable to attack.

Given the environmental conditions, the existing and growing Soviet capability, it is apparent that we will continue to have urgent requirements for systems capable of successfully operating on a complex battlefield, regardless of the environment. We need systems for both air-to-air and air-to-surface applications that will allow our forces to find, engage, and destroy hostile ground and airborne targets. Only those forces which are capable of operating in night and adverse weather will be relevant to the outcome of the battle. All others may just become targets as they wait for the weather to clear sufficiently so they may be employed.

PROMISING NEW SYSTEMS AND TECHNOLOGY PROGRAMS

We have a number of promising technology efforts and new system programs in development which will improve our capability to operate in night and under adverse weather conditions. For the air-to-air mission, we are pursuing the development and deployment of the advanced medium range air-to-air missile (AMRAAM) to provide the beyond visual range, all aspect capability required for the scenarios where our forces may find themselves outnumbered. The AMRAAM program is currently in the middle of its 33-month validation phase, during which each of the two contractors, Hughes and Raytheon, will demonstrate ten full-scale missiles against specified targets. The program is proceeding very successfully.

In the air-to-surface arena, we have fielded the PAVE TACK system to provide limited night and weather capability for our F-4 and F-111 aircraft. To provide additional capability, we have an engineering development effort which is developing a low altitude navigation and targeting infrared system for night, or LANTIRN system. LANTIRN is developing a holographic Head Up Display (HUD) and two pods for our F-16 and A-10 aircraft. One pod provides navigation while the other performs targeting. LANTIRN assists the pilot of a single seat aircraft to fly at night and under the weather. The system also helps the pilot in acquiring targets and readying the weapons for launch. This assistance helps to relieve pilot work load and allows him to concentrate more on flying the aircraft.

New night attack avionic subsystems, such as PAVE TACK and LANTIRN, enable us to operate more effectively during night visual conditions. In certain cases, it gives us the ability to operate during limited weather conditions. The addition of just nine and one-half hours of night visual capability will more than double the time available for us to apply firepower in areas such as Europe.

PROGRAMS PROVIDING ALL WEATHER OPERATIONAL CAPABILITY

We are also pursuing a number of other technologies and systems to complement LANTIRN. To provide a more complete "all environment" capability, we are developing high resolution synthetic aperture tactical radars and millimeter wave radars which will improve target recognition, resolution and navigation. With these enhanced capabilities, we can also take better advantage of target location data derived from other systems.

One example is the PAVE MOVER, which coupled with compatible munitions, can add another dimension to our all weather attack capability.

We are also developing a standoff system, which is known as the Precision Location Strike System, or PLSS, to give us the much needed capability to accurately detect, locate and classify emitting targets in all weather conditions. These targets can then be attacked and destroyed by either standoff weapons or by manned aircraft. PLSS was developed to counter sophisticated air defense systems, which utilize numerous radar controlled SAM and GUN systems. It is an integrated emitter location and strike system, which utilizes time of arrival (TOA) to provide continuous, wide area coverage in a dense emitter environment.

Highly accurate weapon delivery results from combining the emitter and weapon delivery portions of PLSS by use of distance measuring equipment (DME) to direct either standoff guided weapons or an attack aircraft. The system can deliver multiple simultaneous weapons in a dense jamming environment, which complements our F-4G WILD WEASEL and the EF-111 surveillance and strike capabilities.

DEVELOPMENT OF COMPATIBLE WEAPONS AND MUNITIONS

The development of compatible weapons and munitions is sometimes overlooked when addressing the night/all weather problem. Parallel development of improved weapons and munitions is necessary to enhance the improvements in new avionics for night and adverse weather penetration. For example, the newest member of the MAVERICK missile family, the Imaging Infrared, or IR MAVERICK, when launched from a PAVE TACK or LANTIRN equipped aircraft, provides a multiple kill opportunity against tanks and armor.

Promising work is going on in the area of new tactical munitions dispensers and Combined Effect Bomblets (CEBs) for target sets that are prone to destruction by area munitions. The Combined Effects Munition (CEM) program provides a munition system consisting of a dispenser with integral fuze, submunitions, proximity sensors, and associated shipping and storage containers. It consists of the SUU-65/B Tactical Munitions Dispenser (TMD) integrated with the BLU-97/B Combined Effects Bomb (CEB). This munitions system will provide both a low and high altitude, low speed through supersonic, delivery capability and reduces the required types of munition necessary to fulfill the air force tactical and strategic missions. CEM is in the final phase of full-scale development (FSD).

Air delivered mines, such as GATOR, can also help to slow the march of the enemy mobile and mechanized ground forces regardless of the environment. The GATOR will consist of small, surface emplaced, antiarmor/antivehicle and antipersonnel Target Activated Munitions (TAMs), and associated Kit Modification Units (KMUs), loaded into air delivered dispensers. Individual TAMs will sense valid targets, reject false targets, and detonate warheads when the targets come within lethal range. The mine fields, surface emplaced, will be difficult to counter.

Operationally, the GATOR system will be suitable for use both in air support of ground forces in combat and for deployment by tactical air forces operating in enemy territory. These weapons will add a capability to deliver instant mine fields to provide disruption, demoralization, and destruction of enemy forces. The GATOR will continue to be at its peak of effectiveness at night and in bad weather, and present a continuous threat until the preselected self-destruct time has elapsed. GATOR is in the final quarter of FSD, presently completing its DT&E/IOT&E efforts. Major tests include: Captain A-10 flight, F-16 ripple and release. The CBU-89/B will be ready for production the first quarter of FY 82.

The Wide Area Antiarmor Munition, or WAAM, is the generic name for a family of weapons which promise to further expand our night and weather capability. One member of this WAAM family is the anticluster munition, or ACM, which is developing improved warheads, sensors, seekers, and dispensers. The ACM (CBU-90/B) integrates an antiarmor, self-forging, multislug submunition (BLU-99/B and the SUU-65B dispensor. The ACM provides an air delivered cluster munition designed to defeat massed armored targets. It is capable of being carried by U.S. aircraft (A-7, A-10, F-4, F-16, F-111) and being evaluated for delivery by NATO aircraft (Jaquar, Tornado, Mirage V, Harrier, Alpha-Jet). After release over specified target areas, there is a timed delay prior to opening of the TMD and dispersion of the submunitions. The dispersal pattern is predetermined by release altitude, r.p.m. rate, and speed. A timed sequence of events begins upon separation of the submunition from its dispenser. During descent, the submunition is oriented and stabilized, and deploys a standoff probe containing an impact sensor. Upon probe impact with a surface, the warhead explodes expelling high velocity fragment streams capable of perforating rolled homogeneous armor (RHA) and providing substantial after armor effects. The standoff probe permits detonation to occur at a height above impact level that optimizes kill probability. ACM is presently in the final phases of its FSD program, and is continuing towards a production decision in FY 83.

Another member of the WAAM family, known as the WASP, is a minimissile which is a lock-on-after launch (LOAL), hit-to-kill, weapon concept capable of independent target acquisition and tracking. The WASP system launches minimissiles singly or in selective salvos from pod launchers on wing store stations of the F-16, A-10, F-111, A-7, F-4 and certain NATO aircraft. Each launcher carries 12 missiles. It is not necessary to acquire the target visually or point the aircraft at the target area. Target planning data are obtained through reconnaissance, surveillance, and other intelligence sources. Target location updates can be transmitted to the strike aircraft through the command and control network, or the aircraft can reacquire and strike the target autonomously. The terminal guidance sensor is programmed to start search and acquire targets after launch. The seeker acquires the target, guides the missile to individual armor target units, and the shaped-charge warhead detonates on impact. The WASP electronics and carrier aircraft interface equipment are contained within the aircraft and the pod launcher. WASP has completed the first third of its validation effort, in which Hughes and Boeing are the competing contractors. AFSARC II decision is planned for the third quarter of Fiscal Year 83.

NEW FIGHTER AIRCRAFT PROGRAMS

Most of the development and technology programs are focused towards adaptability to future generations of fighter aircraft. We are looking at derivatives of existing aircraft, such as the F-15 Strike Eagle and the F-16 XL, for the mid to late eighties. We are also currently conducting concept definition studies for the next generation fighter for the mid-90s. There are a myriad of areas we are looking into to insure we examine all of the possible avenues required to operate effectively throughout all conditions of combat. These efforts are directed toward providing improved capability for our forces to detect, locate, and destroy targets while denying the enemy sanctuary during periods of darkness and adverse weather.

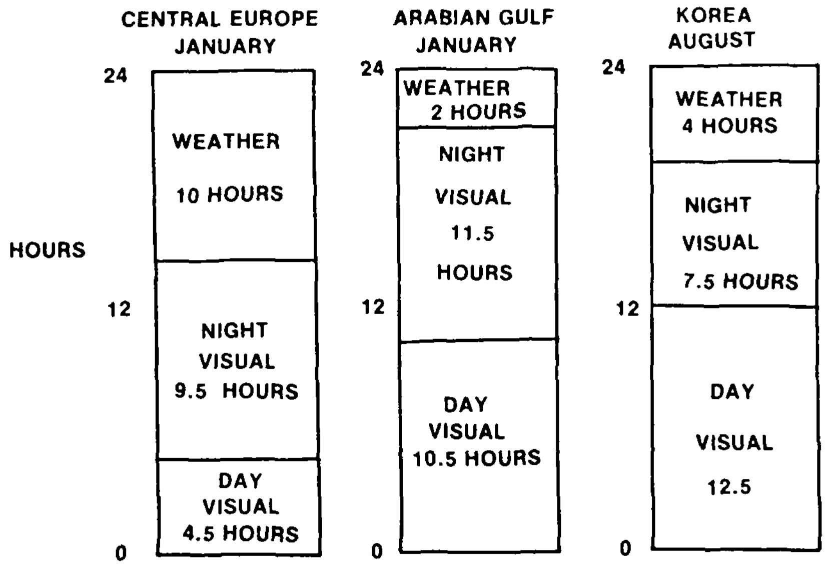
CLOSING NOTE OF CAUTION

As a closing note of caution, we must not allow our pursuit of better night and adverse weather capabilities to be slowed as we begin to field new weapons and improved subsystems. We must not be lulled into a false sense of security because our potential adversaries continue to aggressively pursue improvements in their capabilities. Therefore, we must do likewise, or else we may be forced to fight under conditions of the enemy's choosing and if we grant him the opportunity. If we cannot operate under certain conditions, we can be certain that it will be during those sanctuary conditions that he will choose to attack. It is imperative that we not permit that to happen. The U.S. Air Force is pursuing an aggressive program in both night and adverse weather weapons and avionics to see that it does not happen.

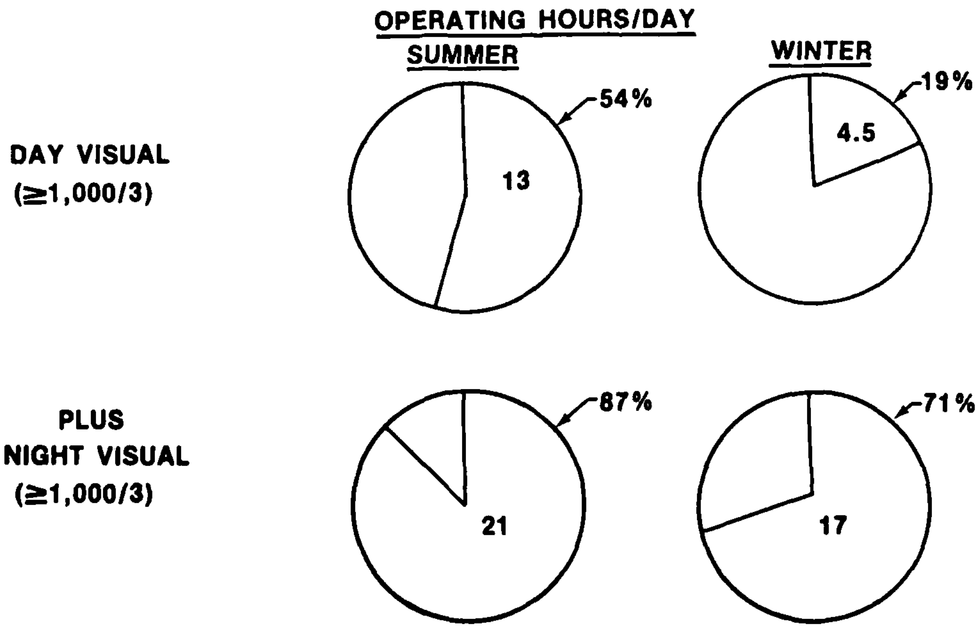
I would like to close by encouraging all of you to promote a vigorous dialog on the problems and potential solutions for enhancing NATO's capability to fight in all conditions of combat and all conditions of weather. It is through conferences and symposia such as this one that we can identify areas and formulate ideas for continued improvements as a result of focusing attention on our common requirements. The program committee should be congratulated on the excellent variety of papers selected for this symposium. They will highlight in more detail the weapons and technological areas I have mentioned this morning in my presentation. I am certain you will all have a most productive and stimulating week.

OPERATING WINDOW

DAY AND NIGHT VISUAL (GREATER THAN 1000 FT /3NM)



CENTRAL EUROPEAN ENVIRONMENT



ATTAQUE AIR-SOL
AXES DE RECHERCHE POUR LES SYSTEMES AEROPORTES

par

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1 - INTRODUCTION

Le but initial de ce papier est de traiter des systèmes aéroportés à l'exclusion des armements eux-mêmes. Cependant ces derniers sont examinés pour ce qui concerne les implications sur les systèmes.

Le point de vue adopté est celui de l'intégrateur de systèmes, au carrefour entre les opérationnels et les équipements.

Aussi ce papier est-il une tentative pour dresser à la fois un tableau des besoins et un tableau de possibilités offertes.

C'est surtout une liste de questions que l'on peut poser sur ces deux aspects, dans le but de rechercher des points de rencontre. Certaines réponses seront je suppose apportées dans la suite des exposés. Bien entendu cette liste n'est pas exhaustive.

2 - CLASSIFICATION DES ARMEMENTS ET DES MODES DE TIR

On propose ici une classification des armements et des conduites de tir. Cette analyse sommaire a simplement pour but de comprendre les relations étroites existant entre le type d'objectif, le type d'arme employé et la conduite de tir associée (comprenant les moyens à mettre en oeuvre dans l'avion et les modes d'utilisation correspondants).

2.1 - Dispersion - coup au but

- Armements de dispersion, avec charge à effets divers dans une zone étendue (au moins horizontalement) c'est-à-dire d'au moins plusieurs dizaines de mètres, voire quelques centaines de mètres. Ils s'emploient contre des objectifs dispersés et pas très durs : groupes de véhicules, installations mobiles...

- Armements "coup au but", nécessitant une précision d'impact de l'ordre de 1 mètre ou au plus quelques mètres. Ils sont employés contre des objectifs ponctuels durs à percer tels que blindages ou protections en béton.

2.2 - Type de guidage

1. Armes balistiques pures

C'est le cas des canons, des bombes conventionnelles lisses, freinées, ou superfreinées.

2. Armes stabilisées

Certaines armes contiennent des capteurs gyro-accélérométriques (verticale, cap) servant de référence à un pilotage sommaire destiné à utiliser l'effet de portance (bombes à compensation de pesanteur par exemple) ou une propulsion (bombes "boostées").

3. Armes à guidage inertiel qui se guident sur des coordonnées de l'objectif transmises à l'arme au moment du tir. On utilise un tel système dans des armes propulsées, donc plutôt à distance importante.

4. Armes autoguidées - Elles incorporent un autodirecteur qui détecte puis poursuit la cible de façon autonome.

Il faut dans cette catégorie distinguer encore plusieurs cas :

- L'autodirecteur est semi-actif, c'est-à-dire qu'il nécessite une illumination de l'objectif. Cette illumination peut être fournie par l'avion tireur lui-même ou par un dispositif coopérant (autre avion, hélicoptère, fantassin...). On peut classer dans cette catégorie également les armes "beam riding".

- L'autodirecteur est passif ou actif, il ne nécessite pas d'illuminateur. Il peut alors être complètement "fire and forget" ou nécessiter encore une participation du tireur pour des opérations de téléguidage, comme c'est le cas par exemple pour un autodirecteur télévision dont l'image est retransmise à un opérateur pour recalage.

Il faut remarquer que l'autoguidage peut être appliqué non pas à l'arme entière, mais à des sous munitions de l'arme.

2.3 - Conséquences sur les conduites de tir

1. Une première considération est relative à l'origine des erreurs au but. De ce point de vue l'essentiel des erreurs pour les armements non autoguidés proviennent de l'avion tireur :

- Erreurs sur les paramètres inertiels (verticale, cap, vecteur vitesse, accélération...) au moment du tir.
- Erreurs d'acquisition de la cible : erreurs de visée de la télémétrie.

On emploie le terme de visée pour l'acquisition de la direction de la cible de manière générale, c'est-à-dire qu'on y rassemble les cas où on a une visée au sens strict mais aussi les cas où on a une détection, une acquisition et éventuellement une poursuite de l'objectif par des moyens autres que la vue directe (radar, électrooptique..). Sous le terme télémétrie on rassemble toutes les mesures qui permettent de compléter les mesures angulaires précédentes par des mesures de distance (télémétrie oblique, utilisation de mesures de hauteur...).

- Autres erreurs telles qu'erreurs sur la connaissance des balistiques réelles, erreurs de quantification et erreurs dues aux cadences de calcul...etc...

Pour les trois catégories d'armes correspondantes la précision va décroître avec la distance de tir.

Par contre dans les cas d'autoguidage l'influence de la part avion est faible.

2. Un second aspect concerne les contraintes apportées par le besoin "d'intervisibilité" avion-cible avant et après le tir.

- Nécessité d'un tir direct

  - lorsqu'il faut acquérir (détecter, poursuivre) la cible elle-même,
  - lorsqu'il faut continuer à illuminer la cible pendant le vol de l'arme au profit d'une arme autoguidée.

- Possibilité d'un tir indirect lorsque seul un recalage sur un point initial est nécessaire, l'arme étant soit une arme de dispersion, soit une arme avec un guidage entièrement autonome (acquisition et poursuite), soit encore une arme avec des sous munitions à guidage entièrement autonome.

Dans ces deux derniers cas le but du recalage est seulement d'amener l'arme dans un domaine où l'acquisition de la cible lui est possible (panier). C'est ensuite l'autoguidage qui permet d'assurer le coup au but de l'arme ou des sous munitions.

3 - EVOLUTION DES BESOINS - ASPECTS OPERATIONNELS

3.1 - Amélioration des précisions au but

a) Autoguidage

Il est certain que l'évolution actuelle fait apparaître un besoin d'autodirecteurs pour les tirs "coups au but", autodirecteurs qui font appel aux différentes branches de la physique (magnétique, millimétriques, infrarouge, télévision...)

Les besoins concernent

- l'adaptation aux différents types de cibles et dans les différentes conditions d'environnement.

- la recherche d'une autonomie des armes vis à vis de l'avion et du tireur.

B) Armes non autoguidées

On peut se poser cependant la question de savoir si l'on ne doit pas continuer à améliorer la précision des tirs balistiques.

- les armes correspondantes présentent un rapport intéressant charge utile/coût
- elles sont disponibles à court ou moyen terme
- elles permettent une grande diversité de charges militaires, donc une bonne adaptation de ce point de vue à une variété de cibles

- l'autoguidage pour être efficace semble nécessiter une étroite adaptation à la fois au type d'objectif et à l'environnement ; l'autodirecteur devient très spécifique d'un cas d'attaque donné. Pour s'adapter aux diverses situations il semble être nécessaire de faire appel à une analyse "multispectrale" qui n'est probablement pas envisageable au niveau des armes, mais l'est peut être au niveau de l'avion.

Mais alors il faut rechercher une très grande précision de tir. Pour fixer les idées on peut évaluer prossièrement trois parts sensiblement équivalentes dans les erreurs au but des conduites de tir balistiques actuelles :

- la part due aux erreurs sur les paramètres inertiels
- la part due à la visée et à la télémétrie (acquisition de la cible)
- la part due aux modélisations et aux calculs.

La recherche d'une plus grande précision passerait par l'amélioration simultanée de ces trois parts.

3.2 - Augmentation de la distance de tir

Il y a avantage à augmenter la portée des armes, à précision de tir donnée, notamment dans le but de se tenir à distance maximum des défenses situées à proximité des objectifs attaqués.

Les moyens sont les suivants :

- Utilisation d'un propulseur. C'est le cas des missiles. C'est aussi le cas d'armements conventionnels du type "boosté".
- Utilisation d'armes balistiques lisses avec un tir en piqué ou en vol horizontal suivi d'une ressource. La passe de tir peut être effectuée avec avantage à partir de l'acquisition d'un point initial distant de la cible, plutôt que de la cible elle même.
- Utilisation de l'effet de portance (bombes planantes ou à compensation de pesanteur).

Cependant cette notion de "stand off" est plus complexe et participe autant d'autres moyens de défilement et d'autoprotection qui seront abordés plus loin.

Il faut par contre se souvenir que l'augmentation de portée rend plus difficile l'obtention de grandes précisions au but, sauf pour le cas d'armes autoguidées. Il y a donc là la recherche d'un compromis.

3.3 - Extension des possibilités vis-à-vis des conditions météorologiques

Il y a lieu de bien distinguer deux aspects :

- missions de nuit
- missions en aveugle (de jour comme de nuit)

parce qu'ils ont des liens différents avec les possibilités techniques des moyens d'acquisition et/ou de recalage.

Il faut d'autre part prendre en considération que les missions à basse altitude peuvent bénéficier de conditions de visibilité "sous la couche" plus favorables.

Enfin les statistiques des conditions de visibilité dépendent des théâtres géographiques envisagés : pour ne pas pénaliser la technique, il faut éviter d'amalgamer des cas opérationnels trop divers.

3.4 - Attaques multicibles

a) Les armes de dispersion sont par nature multicibles.

b) Des considérations sur l'efficacité d'une mission avion, contre des chars compte tenu des défenses adverses, conduisent à penser qu'il y aurait avantage à pouvoir détruire plusieurs cibles au sol au cours d'une même passe de tir avec des armes coup au but (dans la mesure bien entendu où ces cibles ne sont pas trop écartées les unes des autres).
On ne peut envoyer un avion détruire un seul char par mission.

Cela est-il envisageable, soit avec plusieurs armes tirées de l'avion, soit avec le tir d'une arme comportant elle-même des sous munitions ? Ces armes ou sous munitions devraient être autoguidées et, pour assurer le multicible, doivent être autant que possible autonomes après tir.

Vu le peu de temps laissé à l'avion pour acquérir les cibles il paraît pratiquement indispensable que l'avion n'ait pas à distinguer à l'intérieur d'un groupement de cibles, sinon peut être seulement pour les dénombrer, et que les munitions puissent elles-mêmes assurer leur affectation aux cibles, éventuellement aidées par le système avion après tir. Ceci peut nécessiter des liaisons avion-munitions après tir.

c) Les objectifs fixes situés en profondeur en territoire hostile peuvent être de dimensions importantes et nécessiter d'y délivrer plusieurs charges sur plusieurs points. Il est donc souhaitable de pouvoir tirer plusieurs armes en salve d'un même avion ou de plusieurs avions groupés. Il faut aussi être capable d'affecter différents points de l'objectif aux différentes armes.

3.5 - Missions préparées - Missions d'opportunité

L'évolution des armements permet d'envisager les tirs indirects avec recalage et sans acquisition directe de l'objectif.

La liberté de choisir des points initiaux convenant aux recalages apporte d'un certain côté une diminution des contraintes, mais entraîne d'un autre côté un besoin accru sur la préparation des missions :

- il faut connaître avec précision les coordonnées relatives point initial-objectif,

- dans le cas où certains autres renseignements sur la cible sont nécessaires (description, image, reconnaissance de signature,...) il faut bien entendu les avoir obtenus d'avance, cela ne pouvant se faire au moment du tir comme lors d'une acquisition directe par un capteur sur l'avion.

L'autonomie accrue des armements, s'accompagne donc d'une plus grande préparation des missions (voir également paragraphe 3.6).

Ceci laisse donc toujours la place à des besoins pour des conduites de tir d'opportunité, quitte à sacrifier d'autres performances (distance de tir par exemple). En particulier la mobilité de certains objectifs renforce ce point de vue. Ce besoin s'accompagne de celui de moyens de détection et d'acquisition autonomes à bord de l'avion tireur, à moins de faire appel à un avion spécialisé en liaison temps réel avec l'avion tireur (voir paragraphe 3.6).

Dans le but de ne pas trop pousser la spécialisation des missions, peut-on envisager que les mêmes armes puissent être tirées en missions d'opportunité comme en missions préparées ?

3.6 - Désignation, acquisition des objectifs. Transmissions

On peut distinguer plusieurs niveaux de renseignements en fonction du facteur temps :

- besoin à long terme de tenue à jour des renseignements tactiques, voire stratégiques ;

- besoin à plus court terme pour le déclenchement des missions et leur coordination ;

- besoin en temps réel d'acquisition et de désignation des objectifs.

Plus on va dans cet ordre plus il faut des délais courts. Cela va jusqu'à la nécessité d'avoir une possibilité de détection et d'acquisition autonome dans l'avion tireur. Mais d'autres voies existent, complémentaires :

- se servir d'avions spécialisés comme évoqué au paragraphe précédent ;

- se servir des autres avions d'attaque comme autant de capteurs intégrés dans un dispositif coopératif.

En dehors des besoins de performances pour les capteurs d'acquisition des objectifs, il faut insister sur la nécessité de disposer de moyens de transmission en temps réel pour :

- la transmission de donnée sur les objectifs (présence, type, localisation, forme ou signatures caractéristiques...),

- la coordination des attaques.

On aboutit au besoin de créer de véritables réseaux.

Cela passe par une étude opérationnelle à faire parallèlement aux études techniques : il faut créer des concepts de hiérarchisation des échanges de données et des ordres d'attaque et de coordination.

3.7 - Contraintes sur les missions

La notion de "stand off" ne doit pas être limitée à celle de distance de tir mais doit être généralisée à tous les moyens permettant de se tenir hors de l'efficacité des conduites de tir adverses, ou de diminuer cette efficacité.

L'environnement hostile d'une attaque air-sol peut comporter des menaces

- sol-air . groupées autour de l'objectif
  . disposées sur le parcours d'attaque

- Air-air qui peuvent se trouver partout et comportent à la fois des chasseurs et des systèmes de veille et de détection au sol ou aéroportés.

La riposte à cet environnement hostile ne peut donc comporter seulement une augmentation de la distance de tir, qui ne serait efficace que vis-à-vis des menaces localisées autour de l'objectif, mais doit aussi faire appel simultanément :

- au vol à très faible hauteur (ou très grande altitude)
- aux contremesures d'autoprotection (détecteurs, brouilleurs, leurres)
- aux brouillages offensifs (missions d'accompagnement spécialisées)
- aux missiles de suppression des défenses (missions spécialisées) sans compter les évasives ou innovations de trajectoire et les armes d'autodéfense.

Remarque :

Le tableau que l'on fait habituellement sur les menaces risque fort d'être très décourageant de par leur densité, leur variété et leur complémentarité.

Il faut procéder à une analyse aussi fine que l'on pourra du fonctionnement des dispositifs adverses pour trouver des moyens efficaces :

- diversification et coordination des moyens d'un même avion,
- coordination des attaques à plusieurs avions.

Il faut d'autre part éviter de se donner, par ignorance, comme contraintes l'enveloppe des menaces possibles, sinon l'obstacle sera trop haut à franchir. Il y a différents champs de bataille qui peuvent poser des problèmes différents (c'est-à-dire conduire à des moyens ou des procédures d'emploi différents), mais tous ne sont pas aussi sophistiqués, tous sont limités dans l'espace et dans le temps.

3.8 - Versabilité des missions

La sophistication des conduites de tir s'accompagne en général d'une spécialisation croissante. Mais on se pose la question de savoir si l'on peut se permettre d'avoir des avions très spécialisés et très différents. Une autre voie consiste à rechercher plutôt des avions communs, avec une base de système commune, et un équipement selon mission. Ceci suppose une architecture qui soit dès le départ conçue en fonction de cet impératif.

On se pose également la question de savoir jusqu'à quel point on doit multiplier les fonctions complémentaires sur un même avion ou si l'on doit rechercher la complémentarité entre plusieurs avions participant à une même attaque.

3.9 - Les postes d'équipage

Une conséquence de tous les points qui précèdent est un accroissement potentiel de la charge de travail des équipages.

Tout d'abord la question monoplace-biplace se pose de façon évidente. La réponse elle n'est pas évidente. En effet la nécessité, pour une flotte de biplaces, de former et de conserver en état opérationnel pendant un temps suffisamment long en cas de conflit un personnel navigant deux fois plus nombreux est un inconvénient non négligeable.

L'évolution des possibilités d'assistance aux équipages devrait limiter les cas ou le choix d'une formule biplace reste inévitable.

Pour ces raisons, il est indispensable de mener très activement les recherches techniques relatives :

- à l'automatisation des processus ; notamment il est indispensable d'automatiser les traitements dans les capteurs (critères automatiques de détection et de reconnaissance des cibles) et les corrélations entre capteurs, opérations "temps réel" de toute façon en dehors des possibilités des équipages aussi nombreux soient ils.

- aux améliorations ergonomiques (visualisations, commandes, confort...)

4 - EVOLUTION DES POSSIBILITES TECHNIQUES

4.1 - Performances des moyens de navigation et de radio-navigation

a) les capteurs inertiels

Les évolutions techniques actuelles tracent principalement deux voies en plus des centrales à plateforme actuelles (classe 1 NM/H, 1 m/s).

- Les centrales à composants liés (strap down). Il semble qu'elles donnent des performances équivalentes aux centrales à plateforme pour ce qui concerne la position, mais des erreurs instantanées plus importantes sur les vitesses (quelques m/s) ce qui est préjudiciable pour les conduites de tir air-sol balistiques ou à guidage inertiel.

- Les centrales à très hautes performances (0,1 à 0,3 m/s), en particulier avec l'utilisation de billes à suspension électrostatique . Peut on réduire corrélativement les autres causes d'erreur, en particulier les erreurs de visée ? Cela pose un sévère problème d'harmonisation.

b) les moyens radio-électriques

Les moyens comme les systèmes I-CNI qui utilisent la multilatération (mesures de distance sur plusieurs balises sol ou plusieurs satellites) sont en développement. Ils procurent des précisions de quelques dizaines de mètres, et pourraient servir à recaler les centrales inertielles de bord en position comme en vitesse (filtrages optimaux), en donnant au système de très hautes performances.

Ces dispositifs semblent cependant devoir être encore très encombrants (même si l'on tient compte du fait que certains d'entre eux peuvent se substituer à d'autres équipements de communication et d'identification).

Les Etats Majors doivent par ailleurs juger de la dépendance qu'ils comportent vis-à-vis d'un dispositif extérieur à l'avion très important.

4.2 - Capteurs de recalage, automatisation

Les moyens de recalage autonomes par rapport au sol, sont nécessaires à toutes les attaques avec acquisition d'un point initial. Par rapport au recalage à vue ils apportent une ou plusieurs des caractéristiques suivantes :

- précision
- possibilité d'utilisation de nuit par temps clair
- possibilité d'utilisation en aveugle

Ils peuvent également être utilisés pour améliorer les performances inertielles (vitesse).

- Les altimètres radar - Ils permettent des recalages par corrélation d'altitude. Ces équipements ont d'ores et déjà des précisions remarquables et couvrent de la basse à la haute altitude. Les moyens de corrélation (processeurs) et les moyens de stockage des hauteurs de terrain (mémoires de masse à bandes, bulles...), font chaque jour des progrès importants qui rendent l'utilisation de ces techniques de plus en plus facile et souple sur toutes sortes de véhicules.

- Les radars de cartographie - La technologie du traitement du signal permet de doter les radars de moyens d'affinage à haute résolution qui améliorent essentiellement la lisibilité des images radar au sol, c'est à dire permettent de trouver très facilement des points de recalage. La précision doit également être améliorée (elle ne s'identifie pas à priori à la résolution).

  Là aussi la corrélation automatique avec des cartes prévisionnelles est envisageable.

- Les moyens électro-optiques - Télévision de jour, FLIR ou line scan de nuit, doivent permettre des recalages de très grande précision sur des détails caractéristiques du paysage par temps clair.

On doit éventuellement associer à ces dispositifs :

- une poursuite (corrélation ou contraste)
- un télémètre laser

Ces dispositifs d'imagerie nécessitent des visualisations tête basse et tête haute pour lesquelles les problèmes techniques et opérationnels restent à résoudre :

- connaissance des paysages utilisables pour les recalages grossiers (pré-recalage) et fins.
- optimisation des séquences de recalage tête basse et éventuellement tête haute
- adaptation des chaînes capteurs, visualisations, oeil, du point de vue des résolutions.

Dans cette catégorie d'équipement on peut également citer le line scan IR, susceptible de fournir un recalage.

Il semble probable qu'il faille avoir recours à une coopération entre les différents moyens radioélectriques électro-optiques .. qui seront ainsi simultanément nécessaires.

4.3 - Capteurs d'acquisition

Les radars de cartographie et les moyens électro-optiques peuvent permettre également l'acquisition des cibles elles mêmes.

- Radars

On peut envisager facilement l'utilisation des radars de cartographie, avec les différentes techniques d'affinage, pour l'acquisition d'objectifs fixes importants (aérodromes, bâtiments...). Par contre des problèmes se posent pour détecter les petits objectifs.

Seules les techniques d'affinage synthétique permettent de descendre à des résolutions de quelques mètres de l'ordre de la taille des véhicules. Cette résolution ne permet pas la reconnaissance et l'identification de ces petits objectifs, qui passent donc par la corrélation avec d'autres renseignements. L'utilisation des signatures radar apportera-t-elle quelque chose ? Ces techniques ne permettent de couvrir qu'un secteur latéral par rapport à l'avion, ce qui est assez peu compatible avec une attaque directe rapide. Par contre cela n'est pas une difficulté pour un avion spécialisé dans la désignation d'objectif en temps réel ou en temps différé (reconnaissance préalable).

La détection de véhicules en mouvement peut être également utilisée. Elle ne peut détecter qu'à partir d'une vitesse radiale minimale, qui augmente lorsque le gisement augmente. Peut on attendre des progrès dans ce domaine ?

- Capteurs électro-optiques

Dans le domaine infrarouge on peut penser utiliser la détection de points chauds.

Etant donné les délais très courts généralement alloués à ces opérations il y a lieu de rechercher une automatisation importante, avec la difficulté de maintenir un taux de fausses alarmes faible. Ceci passe par l'utilisation de techniques de reconnaissance de signatures qui nécessitent encore des développements importants. Si elles aboutissent, une retombée possible sera la transmission éventuelle des signatures à l'autodirecteur de l'arme (ou des armes) ce qui peut aider à le rendre complètement autonome après tir.

Ces développements conditionnent la faisabilité de tirs multicibles.

Là encore il est probable qu'il faille faire appel à une coopération entre les différents moyens, pour créer en fait un capteur multispectral permettant une détection efficace dans l'ensemble des conditions d'environnement de brouillage et de leurrage.

Remarque sur les attaques à basse altitude

L'utilisation de ces moyens est envisagée surtout à basse altitude, d'autant plus basse qu'on se rapproche des objectifs.

Cette contrainte limite notablement les portées de détection possibles. Ajoutée au besoin d'augmenter les distances de tir, elle conduit à envisager plutôt des attaques avec point initial, donc sans acquisition directe des cibles.

Toutefois, si les processus d'acquisition des cibles pouvaient devenir fiables et automatiques, ils permettraient de parler d'attaques d'opportunité, au sacrifice des distances de tir, ou des altitudes de vol.

4.4 - Réseaux de transmission

Des réseaux de transmission à accès multiple sont en développement. Citons :

- le JTIDS
- le SINTAC

Ils comportent fréquement des possibilités intégrées de navigation et d'identification (I-CNI) déjà évoquées.

Deux voies d'approfondissement semblent être nécessaires :

- la simplification et la réduction des contraintes d'installation pour les avions les plus petits, en particulier les avions d'attaques

- l'étude des possibilités de sous réseaux, de compatibilité entre réseaux et entre sous réseaux, dans le but de pallier la lourdeur résultant du besoin implicite de standardisation et uniformatisation au niveau de zones géographiques très importantes.

4.5 - Gestion tactique des missions et coordination de tous les moyens de bord

De l'examen des besoins opérationnels et des techniques évoquées jusqu'à présent, il ressort un besoin impératif de traitements sophistiqués des données à bord des avions :

- l'obtension de performances passe par le couplage entre plusieurs capteurs d'un même avion
- l'avion d'attaque est intégré dans un système plus vaste qui nécessite la transmission et la gestion d'informations nombreuses
- la plus grande partie de ces opérations ne peut être confiée aux pilotes.

Du point de vue des moyens de traitement numérique embarqués cela signifie que les volumes des mémoires de programme et les charges de calculs correspondant à des fonctions intégrées ne va cesser de croître. Cela concerne plus particulièrement les traitements logiques (par opposition à algorithmiques). Cette évolution semble tout à fait compatible avec les progrès permanents de la technologie dans ce domaine.

Une place particulière peut être réservée à l'utilisation de mémoires de masse permettant de stocker soit des données, soit des programmes à charger dans les calculateurs en fonction des missions et même des phases de mission.

4.6 - Visualisations, commandes, aménagement des cockpits

Ce domaine est fondamental pour l'avenir des avions d'attaque et il concerne directement l'avionneur.

C'est un domaine où les progrès sont nécessaires en permanence pour répondre aux besoins d'assistance au pilote sur lequel on a déjà insisté.

Il recouvre deux aspects.

a) Un aspect technique auquel une séssion particulière du présent symposium est consacrée. Je ferai aussi référence au symposium de Stuttgart de Mai 1981 (guidance and control) et au prochain de Blackpool en Avril 1982.

On retiendra plus particulièrement quelques évolutions d'importance :

- augmentation des champs viseur tête haute
- recherche de nouvelles technologies d'écrans rendues d'autant plus nécessaires que le nombre des écrans nécessaires augmente (encombrement, consommation...)
- recherche d'architectures compatibles des problèmes de sécurité et de redondance, en particulier pour ce qui concerne les liaisons avec les capteurs nécessaires au pilotage
- utilisation de la commande à la voix
- aménagement des cockpits pour l'utilisation des forts facteurs de charge et des hautes incidences.

b) Un aspect logiciel qui rejoint l'aspect précédent de gestion et qui vient accroître le volume des logiques nécessaires. Il s'agit en effet à tout instant d'affecter les commandes disponibles aux fonctions en cours et de ne visualiser que les informations valides (c'est-à-dire tenant compte des états de bon fonctionnement) nécessaires à la réalisation de la phase de mission.

4.7 - Systèmes pour le vol très basse altitude

a) Un premier point concernant les possibilités de vol à très basse altitude est relatif aux commandes de vol.

Les avions modernes, et cette caractéristique va se généraliser dans l'avenir, sont dotés de commandes de vol électriques avec un niveau de sécurité très élevé.
Cela a deux conséquences :

- ce ne sont pas les commandes de vol qui apportent une limite du point de vue de la sécurité, que ce soit en pilotage manuel ou en pilotage automatique. Cela veut dire que, par exemple en pilotage manuel à vue, il y a un taux de pannes catastrophiques négligeable dans la chaîne aval chargée de l'exécution des ordres du pilote ;

- l'adjonction des circuits nécessaires à des fonctions suivi de terrain automatique aux commandes de vol électriques représente un pourcentage faible de matériel.

b) Les principes de vol basse altitude les plus simples tels que :

- évitement d'obstacle, avec fonction découpe dans un radar de nez
- suivi d'altitudes programmées

voient leur efficacité accrue du fait des améliorations sur les capteurs inertiels et sur les systèmes de navigation en général.

En effet les hauteurs de vol seront d'autant plus faibles que l'information de verticale sera précise et sûre et que la position sera connue à chaque instant avec précision.

On peut imaginer qu'à la limite si la position était connue avec grande précision et de façon sûre et si le relief de tout le parcours pouvait être mis en mémoire, on pourrait réaliser des vols basse altitude sans capteur particulier.

Ce ne semble cependant pas envisageable pour des vols très basse altitude. Il faut donc des capteurs pour détecter les obstacles.

c) Les systèmes de suivi de terrain au sens strict qui existent aujourd'hui comportent, avec les redondances et sécurités nécessaires, une détection du profil de terrain par radar et un calcul d'ordre de facteurs de charge pour suivre "au mieux" ce profil. Puisqu'il s'agit d'exécuter en permanence un ordre calculé les systèmes d'exécution automatique de ce pilotage sont très bien placés.

Par rapport à ces systèmes une voie de recherche intéressante consiste en une diversification et une complémentarité des moyens de détection de sol, utilisant notamment, en plus ou à la place du radar de nez, des capteurs électro-optiques, ce qui suppose qu'on accepte une limitation des possibilités vis-à-vis de la météo, qui paraît raisonnable si l'on prend en compte les conditions au ras du sol.

Cela passe également par une modulation des hauteurs minimales recherchées sur les différents éléments du parcours, et par une intervention plus grande du pilote dans les phases les plus basses.

Le but recherché dans l'utilisation de ces nouvelles techniques est double :

- diminuer le coût des systèmes
- diminuer les hauteurs de vol dans les zones les plus critiques.

5 - CONCLUSION

L'analyse des menaces fait apparaitre un obstacle très élevé devant nous.

L'analyse des besoins opérationnels montre qu'il est nécessaire de disposer d'un ensemble de moyens complémentaires et il ne parait pas possible de négliger une catégorie de moyens sans se pénaliser fortement.

L'analyse des possibilités techniques montre qu'il y a beaucoup de voies possibles que peut être la plupart sont nécessaires, qu'en tout cas il est impossible d'effectuer des choix définitifs avant longtemps.

Il faut donc être très ambitieux et très tenace. Mais il faut aussi s'efforcer de dégager au fur et à mesure des recherches des voies pratiques, réalisables à relativement court terme, sans vouloir attendre de "tout avoir".

SOME POTENTIAL NOVEL APPROACHES TO THE AUTOMATIC AIRBORNE DETECTION AND IDENTIFICATION OF GROUND TARGETS

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SUMMARY

Some optical techniques are reviewed in the context of their potential application to the automatic airborne acquisition of targets such as vehicles in the tactical combat area.

1. INTRODUCTION

At a recent conference on image and sensor data processing for target acquisition and recognition, it was noted that (R. Voles, 1980) "on the device side, there seems to be a tremendous incentive to invent three dimensional solid-state structures with a facility for extensive interconnections. The fact that optical devices have an inherent facility for multiple connectivity suggests that they may well have an important part to play in the future". It is as well to appreciate that this remark resulted from consideration of what can now be understood of the capability and functioning of the eye and brain; the remarkable human capabilities for recognition of objects being attributed in part to the very large number of interconnections between each neuron.

The concept of using optics in order to extend the capability of sensors in the area of automation of the detection and identification tasks is, therefore, examined more closely in the following discussion. The results are of particular significance to the automatic acquisition of targets, such as military vehicles, in the tactical combat area. However, as with all such techniques, the potential applications are many.

It must be emphasised that it is not the intention of this discussion to describe a particular developed or even developing system. Instead of this, a number of concepts derived from research in optical processing will be examined together with their implications. Recently there have been a number of excellent reviews covering the subject and these have, therefore, generally been referenced as a guide to the source material.

2. SENSOR OPERATION

In comparison to animals, aircraft optical sensors are clumsy and primitive. Man, for example uses a wide spectrum and intensity of available light and is able to move both head and eyes in order to seek out, identify and estimate the range of various targets. Such an unobtrusive mode of sensing is obviously desirable in the battlefield and, therefore, it is worth attempting to develop sensor architectures which at least emulate some of these capabilities.

It is also to be hoped that human ingenuity might even enhance some sensing modes by using effects which have not been exploited in mans own visual system such as the polarized nature of light and radiation outside the visible range.

Hence, the object is to discuss a passive, imaging sensor system.

3. SENSOR PROCESSING FUNCTIONS

The basic processing functions to be discussed are illustrated schematically in figure 1. Each of these functions needs to be briefly examined in order to establish the type of operation to be conducted optically. Some potential optical techniques are then discussed in Section 4.

As a basic philosophy, it is considered that if optical techniques are to be fruitfully employed in this type of problem, it is essential to minimise interfaces in order to reduce the size of the device, improve reliability and inspectability, and to conserve signal power during processing. Similarly, the enormous parallel processing capability of optical techniques can best be utilised if operations are conducted as far as possible on total images.

3.1 Receiving Optics

It will be assumed that the receiving optics will be a high quality imaging sub-system (or systems). A more versatile system results if provision is made for a measure of stabilisation to these optics and also perhaps for steering and zooming onto potential targets.

3.2 Optical Signal Decomposition

A number of optical atmospheric transmission windows exist and it is presumably no accident that most animals have sensors operating efficiently in the visual light wavelengths (i.e. 0.4 to 0.75 microns). However, in battlefield conditions, smoke, cloud, fog and dust strongly attenuate light in the visible region. The attractions of "thermal imaging" in target acquisition together with the better penetration capabilities of the infra-red and millimetric wavelengths have, therefore, caused

a considerable concentration on these regions in recent years. In particular, the 8 to 14 micron region has the advantage that classical optical elements can still be used and reasonable photodetectors, such as mercury - cadmium telluride, which cover the region exist. Even limiting the sensor operation to such a region does not exclude the treatment of colour in this reasonably wide frequency range. Hence, on the assumption that there is a massive processing capability available, it would seem reasonable to decompose the image using appropriate band-pass filters (or alternatively by using sensors covering different spectral regions). This is shown schematically in figure 2 which also illustrates a second aspect of signal decomposition not frequently considered in aircraft optical sensors, that is polarization.

In the visible spectrum (Walraven, 1981), exploitation of the polarization of scattered radiation as an aid to image analysis has been suggested because in general, radiation due to single scattering can be quite strongly polarized and the smoother the surface, the nearer to the theoretical polarization effect. Man-made surfaces are generally smooth and, therefore, tend to produce larger polarizations than natural surfaces. It has also been observed that darker surfaces also produce larger polarizations, multiple reflections result in small polarizations and as soil moisture increases, it approximates more closely to the behaviour of a smooth surface. Such aspects may assume importance when the light energy is not generated directly by the object being observed. For example, in the case of thermal imagery, polarization analysis could have significance when illumination by some IR source at a distance from the target is used. Some consideration of analysis techniques using polarized light would, therefore, appear appropriate.

3.3 Image Pre-Processing

Image pre-processing is used to improve the quality of the image both for display and acquisition computation purposes. In order to do this, a growing number of analytic techniques are developing aimed mainly at digital processing (Jain, 1981). Some of these methods can be envisaged in terms of filters which provide a measure of image smoothing, enhancement and restoration. For example, the smoothing problem can be defined as the technique required to achieve the best linear mean square estimate of the image function given observations contaminated by white noise which is independent of the image. A number of digital filters for this have been described and an optical implementation based on a suitable filter transfer function may be achieveable. Other filtering techniques include spatial filtering to correct for optical system and sensor defects, unsharp masking which enhances the edges by forming a low pass version of the image and subtracting this from the original and homomorphic filtering, which uses a linear high pass filter on the logarithm of the image function to reduce the effect of variations in illumination. The latter filter is useful in reducing the effects of shadowing. The illumination component has a large dynamic range when there are shadows present whilst that due to reflections is very much less, but modulates the contrast. Hence, the homomorphic filter effectively reduces the dynamic range present in a scene illuminated by incident radiation whilst at the same time effectively enhancing the contrast (Yndstad, 1980).

3.4 Display Prepreparation

Whilst such techniques are a necessary preliminary to display and information extraction, other methods are also needed to handle the multiplicity of information channels into which the received signal can be decomposed. As well as the different spectral information, methods of analysing the polarization effects require formulation. In the latter case, Walraven (1980) has suggested that a good starting point is to employ the Stokes parameter representation. These parameters, which are normally expressed as a four component column vector, $[S_0, S_1, S_2, S_3]^T$, are defined in terms of the amplitudes E_x and E_y of the two orthogonal components of the electric field vector in a local coordinate plane perpendicular to the electromagnetic radiation propagation direction, and the phase angle γ between E_x and E_y as follows:-

$$S_0 = \langle E_x^2 \rangle + \langle E_y^2 \rangle \qquad S_2 = 2\langle E_x E_y \cos\gamma \rangle$$
$$S_1 = \langle E_x^2 \rangle - \langle E_y^2 \rangle \qquad S_3 = 2\langle E_x E_y \sin\gamma \rangle$$

Of these, S_3 is usually negligible in natural scenes and will, therefore, be ignored.

If a polarizer is set with its axis at an angle α to the local x axis, the transmitted intensity is:

$$I(\alpha) = \langle E_x^2 \rangle \cos^2\alpha + \langle E_y^2 \rangle \sin^2\alpha + \langle E_x E_y \rangle \sin 2\alpha \qquad (1)$$

It follows after some manipulation that:-

$$\begin{aligned} S_0 &= I(o) + I(\pi/2) \\ S_1 &= I(o) - I(\pi/2) \qquad (2) \\ S_2 &= 2I(\pi/4) - I(o) - I(\pi/2) \end{aligned}$$

These parameters can be presented in a number of ways. For example, the degree of polarization P is defined as:-

$$P = \frac{[S_1^2 + S_2^2]^{1/2}}{S_0} \qquad (3)$$

Where in (2) and (3), it should be noted that the Stokes parameters, the intensities and P are all functions which vary over the coordinates of the image plane (u,v). P itself could be used as the displayed parameter, in which case, the displayed intensity I_d would have the form

$$I_d(u,v) = a + b\,P(u,v) \qquad (4)$$

where a and b are constants. The usefulness of such an approach may be more readily appreciated by observing that the range of P is zero to one and also that the image is normalised at each point by the local total intensity S_0.

A recent approach to the display of the information contained in the Stokes parameters has been proposed by Soloman (1981) and is based on the use of colour. In order to do this, a perception space model of the human visual system is employed (due to Faugeras, 1979) and the Stokes vector $[S_0, S_1, S_2]^T$ is mapped directly into the perception space parameters, brightness, hue and saturation. The Faugeras model enables these parameters in perception space to be transformed into a tristimulus space and from thence into the three colour display primaries.

In a ground attack aircraft, a multiplicity of displays needs to be avoided. For target notification purposes in a single seat aircraft, it is desirable that the HUD is employed. If multispectral information from outside the visible region is to be presented as well as polarized light and other data, it is likely that colour will need to be considered in order to multiplex the information through to the pilot. This colour display needs to be comprehensible and at the same time give reasonable registration with the outside world. The achievement of this will require a good understanding of the human visual system and although considerable strides have been made (Granrath 1981), this area is still very fertile ground for research.

3.5 Acquisition Computation

Acquisition computations involve the emphasising of potential targets and the suppression of the background (detection) the initial screening of these potential targets and the acceptance of those which can be ascribed to a real target catalogue with a reasonable level of confidence (recognition) and finally, the classification of the target with a confidence level which would be set according to the type of mission (identification). In a truly automatic system, identified targets would then be displayed in the cockpit and transmitted to the aircraft system, weapons and sensors. However, such a degree of automation may not be achievable with an acceptable level of confidence, in which case it may be required to display recognised or detected targets to the crew.

A method of extraction of potential targets which may lend itself to optical treatment is the examination of differences in images formed in different ways. The Stokes parameters S_1 and S_2 may be suitable in this respect for the examination of polarization effects and it may in addition be possible to exploit differences in total intensity information obtained at different wave bands. Such operations would best be conducted on the total images if the true power of optical processing is to be realised.

A technique which again can lend itself to some measure of optical processing is that of invariant moments (Hu, 1962). This statistical method uses moments referred to a pair of uniquely determined principal axes to characterise each pattern for recognition where a "moment" is defined by

$$m_{pq} = \iint u^p v^q \, I(u,v) \, du\,dv \qquad p, q, = 0, 1, 2, ---- \qquad (4)$$

and a "central moment" by

$$\mu_{pq} = \iint \tilde{u}^p \tilde{v}^q \, I(u,v) \, d\tilde{u}\,d\tilde{v} \qquad \tilde{u} = u - m_{10}/m_{00}, \; \tilde{v} = v - m_{01}/m_{00} \qquad (5)$$

It can be readily demonstrated that central moments are invariant under translation. Furthermore, Hu has demonstrated that certain algebraic combinations of these moments are not only independent of image position, but also of size, orientation and aspect. These moment invariants may be listed as M_{kl} where "k" refers to the "k" th moment invariant and "l" refers to the "l"th object on an identification list. If the observed moment invariants are M_k, then a computational routine suggested by Hu is to determine the vector magnitudes

$$D_l = [\sum_k (M_k - M_{kl})^2]^{1/2} \qquad (6)$$

If D_l is less or equal to some pre-determined recognition level L_l, a potential target is indicated. Whilst this technique has the attractions that it reduces the target catalogue to simple numerical quantities and its discrimination capabilities can be adjusted by varying the number of invariant moments employed, it would seem essential to ensure that the background of the target is properly supressed and schemes for dealing with multiple targets would be required.

An alternative approach is the use of correlation techniques. If an appropriate representation of a target can be achieved, cross correlation of this and an observed image can be used. Optical methods for accomplishing this which can be independent of rotation, translation, scale and aspect of the target are being developed (Caulfield et al, 1980) and require the production of an appropriate optical filter or reference image. Such techniques should be much less sensitive to the background than those based on invariant moments and can deal with multiple target situations. There is scope for varying their sensitivity by the astute selection of the spatial frequency range employed.

3.6 Range and Bearing

Provided the orientation of an imaging sensor is known, locations on the display can be calibrated in terms of the bearing θ relative to it. It can then be appreciated from figure 3 that if the velocity v is known and reasonably constant and the sensor is stabilised against rotation, a range estimate R can be made for targets close to the aircraft track from the change in bearing noted after a small time increment Δt has passed from

$$R = v \frac{\Delta t \sin\theta}{\Delta\theta} \qquad (7)$$

A real situation would normally be much more complex with aircraft manoeuvres and ground undulations requiring appropriate error correcting action. However, the example given shows that provided target regions can be correlated at times t and $t + \Delta t$ in an imaging sensor, range and bearing estimates can be made. Alternatively, employing a fixed bearing and a stabilised sensor provides a method of observing terrain gradients for passive terrain following.

4. PROCESSING ELEMENTS

It has previously been noted that optical methods can provide a high level of connectivity in processing and if advantage is to be taken of this, it would seem essential that processing operations are performed on the entire image. However, there are currently limitations on the types processing functions which can be performed on total images and, therefore, digital methods are likely to be necessary and desirable in order to enhance the optical processing capability. There is evidence that very fast all-optical digital processing is possible and, therefore, some mention has been included in the following discussion.

4.1 Coherent Transform Optics

There exist many excellent reviews describing the Fourier transform properties of spherical lenses and mirrors (Casasent, 1978 for example) and, therefore, in the following discussion only a few relevant examples of coherent transform techniques will be discussed. To simplify the notation, small letters will be used to denote electro-magnetic wave complex amplitudes in the input and output planes whilst capital letters will denote the values in the transform planes. The basic lens property to be used is illustrated schematically in figure 4, where it can be seen that an object image in the input focal plane of the lens is Fourier transformed into the output focal plane. For this purpose, the input plane is illuminated with a coherent plane wave from a laser source. A similar effect results if the lens is replaced by a spherical mirror. A two lens coherent optical Fourier processing arrangement is shown in figure 5. If a filter $G(U,V)$ is inserted in the Fourier Transform plane of this arrangement, given an input $f(u,v)$ the result at the output plane is (ignoring a constant multiplier)

$$f(r,s) * g(r,s)$$

That is, the convolution of f with g. Different coordinates have been used to indicate the scaling and inversion effect of the lenses. If the complex conjugate of G is used, (expressed as G^*), the result is then the correlation of f with g (expressed as $f \circledast g$). G^* is described as the matched filter for g. Other uses of the Fourier transform plane include the insertion of filters to selectively remove spatial frequencies. For example, the simple case of a low pass filter is a circular hole in an opaque screen. Alternatively, $g(u,v)$ may have the form $u^p v^q$ which permits the extraction of the moments in equation (4).

It can be seen from this brief discussion that much of the power of this technique is in producing appropriate matched filters. Considerable strides have been made in this area recently (Caulfield et al, 1980) and the understanding of the requirements for the design of filters which can provide an appropriate generalised representation of a target discussed in 3.4, is well advanced. Such techniques have the additional benefit of maximising the signal to noise ratio if a target is present. Furthermore, if it is unnecessary to display the processed image, much of the pre-processing can be conducted at the same time as the acquisition computing. Flexible filter design and implementation (by optical and computer techniques) is an area in which successfull research could provide wide ranging benefits.

4.2 Holographic Methods

Holographic methods are frequently used for producing the matched spatial filters discussed in 4.1. An example of an approach which obviates the need for forming a separate filter is the joint transform correlator illustrated schematically in figure 6. In this, the two functions to be correlated are simultaneously Fourier transformed and the resultant intensity recorded as a hologram. The intensity can then be expressed as

$$I(U,V) = G + F + GF^* \exp(-4\pi iUb) + G^* F \exp(4\pi iUb) \qquad (8)$$

where the input function is expressed in the form $g(u-b) + f(u+b)$ and I is given by the product of the transformed amplitude with its complex conjugate. If (8) represents the reflectance of the hologram so formed, the resultant output is then of the form

$$q(r,s) = g \circledast g - f \circledast f - g \circledast f * \delta(r-2b) + f \circledast g * \delta(r+2b)$$

where δ is the Dirac delta function.

If g is a region of f recorded at a time increment Δt before f itself is recorded, the displacement of g relative to the same region in f can be found from the location of the correlation maxima. This information would be required for range and bearing estimation (3.6). There are considerable possibilities for this technique in target acquisition computing.

A method which has been shown to provide a means of subtracting images to indicate where differences have been introduced is holographic subtraction (Bromley et al, 1971). The principles of this method are illustrated in figure 7. Initially a hologram is formed of the phase object, which in this case is the image of interest. This image is then replaced by the second one in which some region is changed. Viewed from the point indicated, this image has the previous one holographically superimposed on it. If now the phase of the beam being used to read the hologram (the upper one in the figure) is now shifted, the brightness of those areas where there is correspondence will go

through minima and maxima as a varying phase change from 0 to 2π is introduced. At a minimum point, areas of difference will distort the wavefront producing a bright spot in a dark background. Whilst this scheme is illustrative of an image subtraction process which has been published in the literature other methods based on the availability of appropriate spatial light modulators which can be written and erased at high speed can be devised.

4.3 Optical Feedback

Although the use of coherent optical techniques for image processing dates from the early 1960's, the use of optical feedback is a comparatively recent innovation (Akins et al, 1980). Only one method will be briefly reviewed to illustrate the power of the technique. This is based on a Fabry-Perot interferometer and is illustrated in figure 8. In this, the input f(u,v) is Fourier transform imaged to the midplane of the confocal system where it undergoes filtering by G. It is then inverse Fourier transformed onto the mid-plane by the second mirror and then a portion (q (r,s)) is coupled out. The remainder is then again Fourier transformed and filtered by H (dotted rays in figure 8) before this feedback portion is again transformed to rejoin the original beam. The coherent transfer function of this feedback system is given by

$$C(U,V) = \frac{K}{\left[\dfrac{1}{G(U,V)} - tH(U,V)e^{i\beta}\right]} \qquad (9)$$

where t is the round-trip amplitude transmittance, K is a constant and β is the phase shift introduced in the feedback loop and is determined by the mirror separation. β can be varied by introducing appropriate phase shifting material. There is considerable flexibility in the way such a coherent transfer function can be formed.

4.4 Real-Time Processing

In order to conduct the type of processing operations described, it is essential that spatial light modulation can be performed in real-time. In order to do this, it is essential to develop fast acting light valves which can be written by both coherent and incoherent light. One approach to this problem (Figure 9) is to use nematic liquid crystals as an electrically tunable birefringent medium (Grinberg et al, 1975). This birefringence is a function of the electric field accross the liquid crystal, which in turn is governed by the input light intensity via a photoconductor (in this case CdS).

The goal of real-time holography has been pursued for some years, early attempts being based on the photorefractive effect in materials (von der Linde and Glass, 1975, Staebler et al, 1975, Pichon and Huiguard, 1981). However, a recent development which would appear to offer considerable future prospects is the use of four wave non-linear optical mixing in holography (Yariv 1978). In this technique, the non-linear medium is pumped by equal and oposite waves (f_1 and f_2 in figure 10). A weaker wave, f_4 is then projected into the plane z = o of the medium. This results in a phase conjugate wave f_3 to be reflected in the -z direction, where $f_3 \propto f_4^*$. Yariv has demonstrated the equivalence of this process to the actions of writing and reading a hologram in real-time. The scheme also has the advantage that f_3 in the -z and f_4 in the + z directions can be amplified by this technique. Other amplifications schemes for coherent optical image processing have been investigated based on dye amplifiers (Akin et al, 1980). Using the four wave nonlinear optical mixing technique, Yariv has proposed the optical processor illustrated in figure 11. In this, the pump waves have impressed on them the amplitudes f_1 and f_2. The conjugate wavefront can then be shown to be

$$q_3 \propto f_1 * f_2 \circledast f_4 \qquad (10)$$

Replacing f_1 by a point source gives the correlation of f_2 with f_4.
Similarly, the correlation of f_1 with f_4 can be achieved by replacing f_2 by a point source. The convolutions can be achieved in the same way.

This potentially very powerful technique is still in its infancy and its proper exploitation depends on many factors, including appropriate materials developments.

4.5 Optical Bistable Devices

Although the theme in this discussion has been to explore the extent to which image processing can be conducted optically on the total image, it must be admitted that there are limits to the application of such a philosophy. Switching operations will obviously be required as well as subsequent processing of the results of optical filtering by perhaps using digital techniques. There are recent indications that optical methods can be employed to advantage in these areas also. This promise has been reinforced by the recent demonstration of optical bistability using non-linear semi conducting optical material in Fabry-Perot resonators and also at non-linear interfaces (Gibbs et al, 1980). Bistable devices could have the potential for very fast operation with the additional advantage of almost instantaneous data transmission.

Such devices have a considerable processing potential (Smith, 1980) and various modes of operation have been suggested including optical memories, pulse shaping, amplifiers, logic elements, analogue to digital conversion, optical triodes and others. Many of these modes of operation have already been demonstrated using hybrid devices in which electrical feedback and the electro optic effect is used to achieve nonlinearity. However, as with the four wave nonlinear device discussed in 4.4, advances in materials technology are required before exploitation can be achieved.

5. DISCUSSION

There are a considerable number of potential optical techniques which could be exploited for the airborne detection and identification of ground targets and it is desirable to examine some of their advantages and disadvantages. The major disadvantage of the optical processing methods is that they could be bulky and they can be very sensitive to missalignment. Both these disadvantages could be minimised with appropriate engineering. An example of this has recently been given (Caimi, et al, 1980) in which the matched spatial filter and Fourier inversion lens have been holographically combined in a correlator.

Although forms of image addition, holographic subtraction, multiplication, optical feedback, differentiation and many other operations can be performed on total images as well as the standard correlations and convolutions, there are still a number of operations which are not easily conducted. Some of the techniques, such as holographic subtraction, could well be too sensitive for implementation on images which may be of poor quality. Hence, there is room for reducing the sensitivity of such holographic techniques and for improving the way in which the images are presented for holographic processing.

In order to provide a summary of the processing approach which could be adopted optically, a breakdown of the types of operations listed in figure 1 against the possible method of optical implementation, where it is available is given in table 1.

If optical techniques are to be used in such applications, further research will particularly be required into:-

- Flexible matched filter design.
- Fast and sensitive light valves with application over different spectral ranges.
- Phase conjugate techniques, especially those employing four wave non-linear mixing.
- All optical bistable devices.
- Optical feedback design.
- Optical subtraction methods.
- Robust, small processors.

In addition, the field generally will particularly benefit from the development of human visual system perception models, especially with a view to exploiting colour displays.

The greatest challenge to the optical techniques is the development of very high speed miniaturised electronic digital systems, custom designed for the purpose of conducting most of the tasks listed in table 1 (or similar tasks designed for digital implimentation). Against this, the great advantage of optical methods is that they are very inspectable, minimise the software requirement and operate at the speed of light. They are also very robust to electrical, magnetic effects and a wide range of electromagnetic radiation. Hence, they could well challenge the very high speed integrated circuit, but are unlikely to do so for at least another decade.

6. CONCLUSIONS

Examination of the current state of technology development in the area of optical sensor processing indicates that the techniques have considerable potential, especially in the field of the automatic airborne detection and identification of ground targets. However, although the potential exists, a considerable research effort is still required if it is to be realised. The end result could be a robust and truly real-time system of considerable capability.

There is a need to support such an activity with adequate modelling of the perception capability of the human visual system if information is to be properly displayed and then utilised.

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TABLE 1

POSSIBLE OPTICAL METHODS FOR PROCESSING SENSOR FUNCTIONS

SENSOR PROCESSING FUNCTION	FUNCTION SUB-DIVISION	POTENTIAL OPTICAL TECHNOLOGIES	TECHNOLOGY STATUS	COMMENT
1. IMAGE PRE-PROCESSING	A. Smoothing	Coherent optical feed-back?	Laboratory technique only Requires fast re-write spatial light modulators, read-out techniques and subsequent processing required (Bistable devices?)	
	B. Unsharp masking (Edge enhancement)	Coherent low-pass filter and image subtraction	Available as a laboratory technique	
	C. Homomorphic filter (Dynamic range reduction and contrast enhancement)	Unknown	Requires optical method of obtaining log (intensity) of the image	High pass filter readily implemented optically
2. ACQUISITION	A. Image differencing (For Stokes parameters etc.)	Holographic subtraction. Image subtraction using spatial light modulators	Laboratory technique only. Holographic method may not be practical unless sensitivity can be reduced and images are specially prepared	
	B. Invariant moment screening	Matched spatial filter (MSF) and off-line vector estimation (Bistable optical devices?)	Appropriate MSF technology has been demonstrated in the laboratory	Requires background suppression and target isolation
	C. Correlation methods	Averaged invariant filter or reference image and optical correlation (Phase conjugate correlator?)	As for 1A Filter development required	Requires filter library
3. RANGE AND BEARING	-	Joint transform optical correlator (Phase conjugate correlator?)	As for 1A - However, the joint transform correlator is a well established technique	
4. DISPLAY PREPARATION	Intensity Normalisation. Colour Display Primaries. Cue Insertions.	Coherent optical feed-back? Digital methods using optical Bistable devices	As for 1A	Method adopted depends on type of display used.

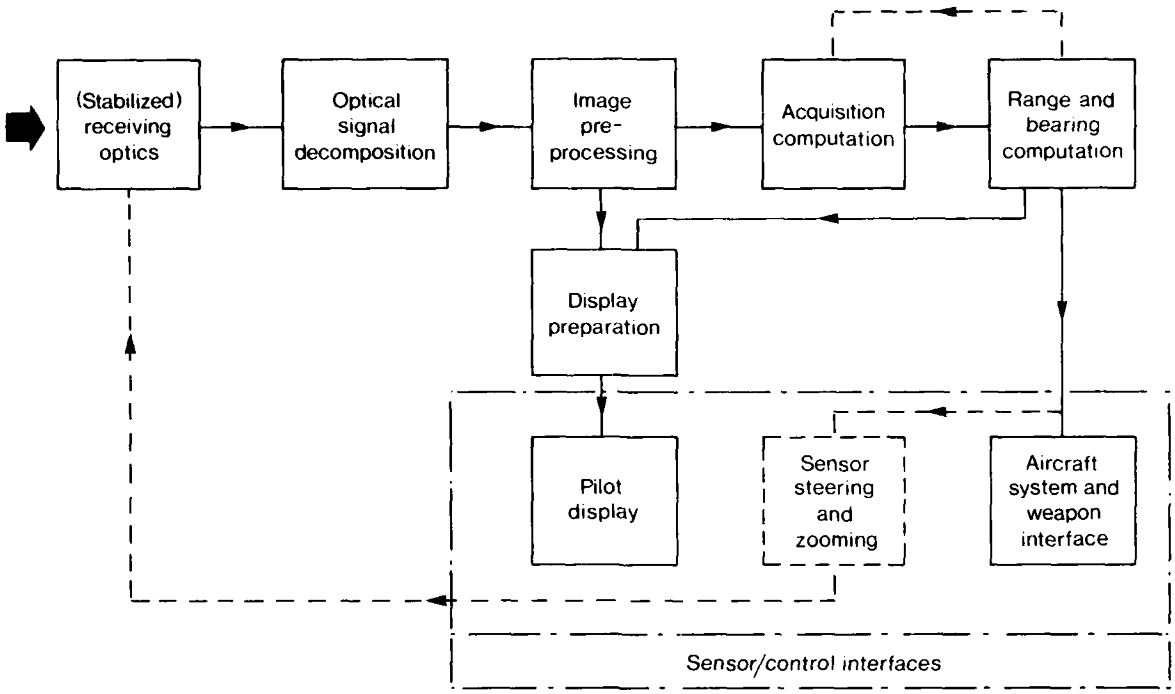


Fig.1 Sensor processing functions

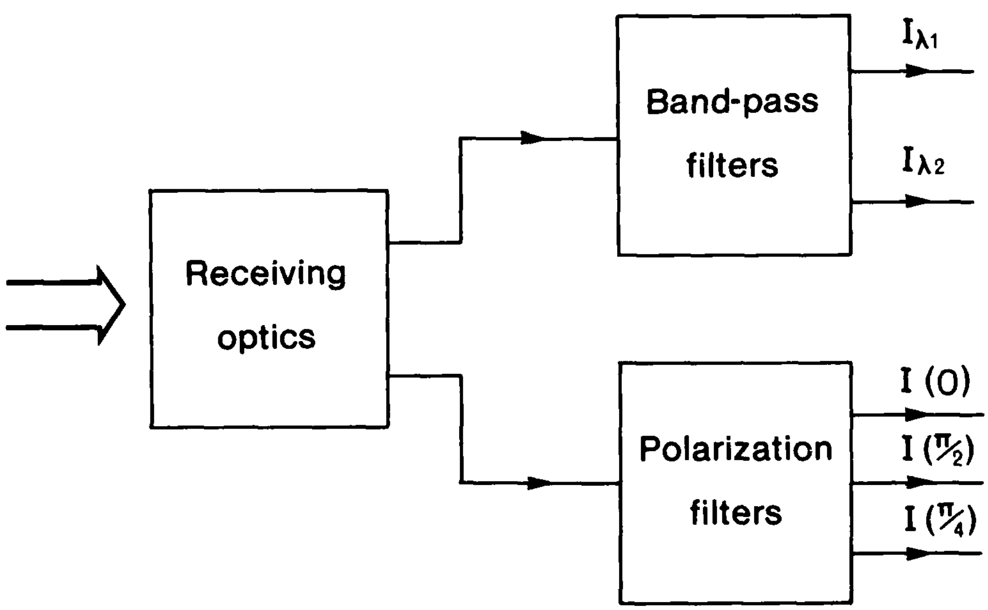


Fig.2 Optical signal decomposition

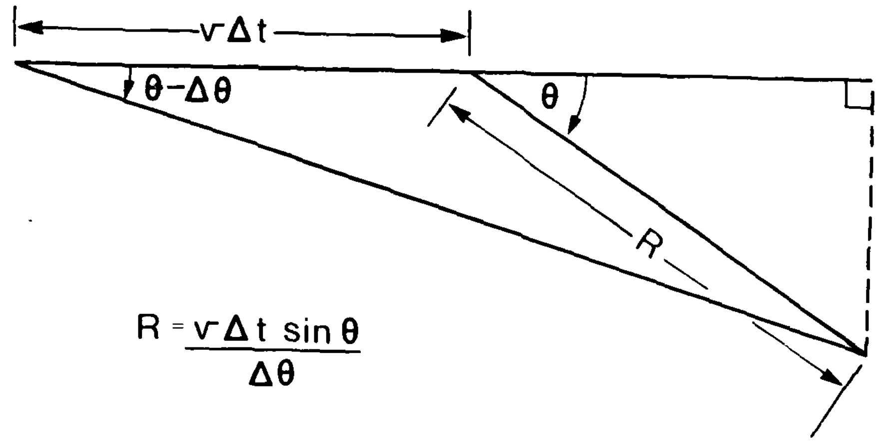
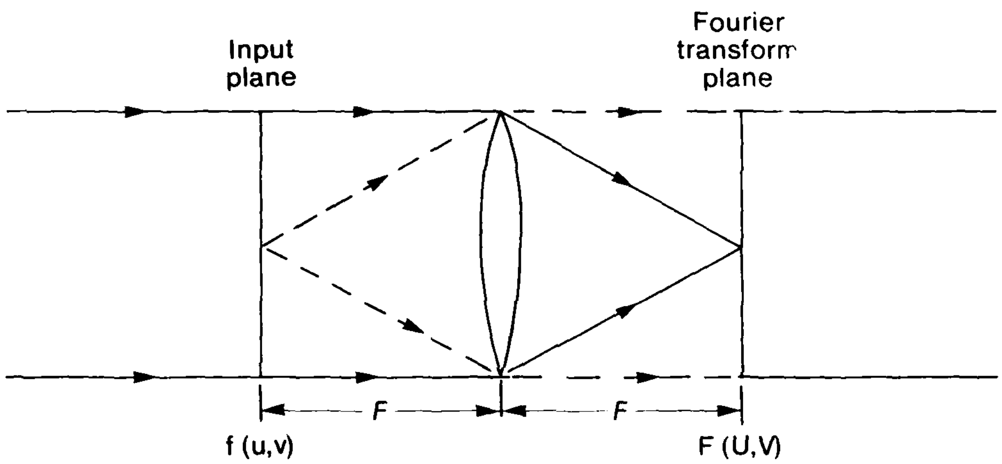


Fig.3 Range and bearing



$$F(U,V) = C \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(u,v) \exp\left[-2\pi\iota (uU + vV)\right] du\, dv$$

C = Constant $\qquad$ F_1 = Lens focal length

Fig.4 Fourier transform properties of lenses

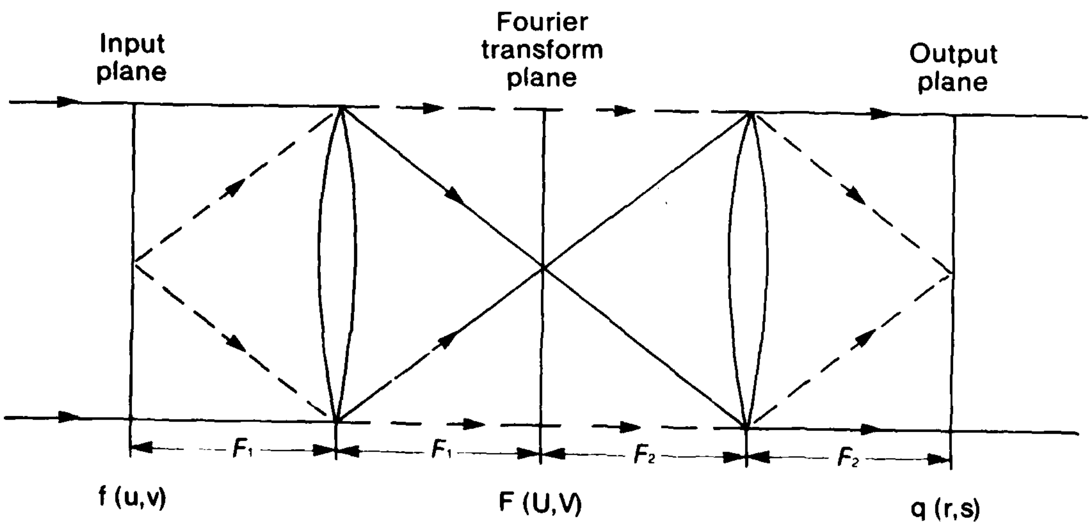


Fig.5 Two-lens coherent optical Fourier processing arrangement

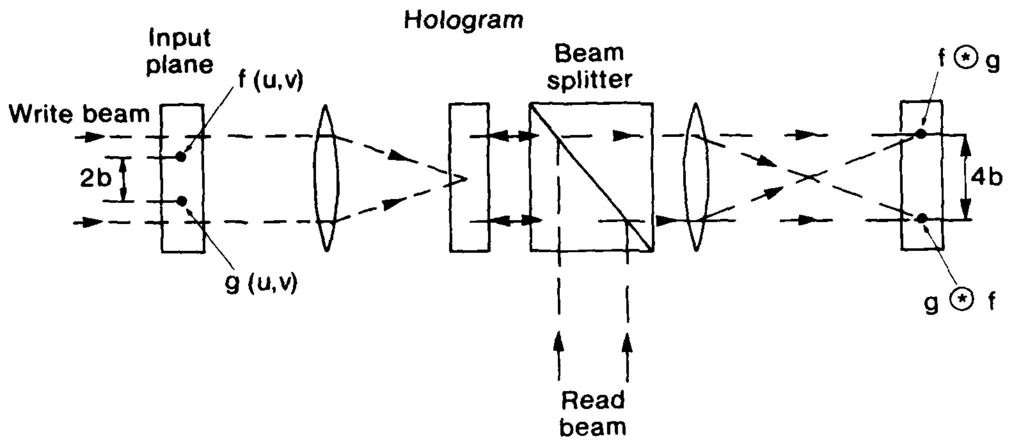


Fig.6 Joint transform optical correlator

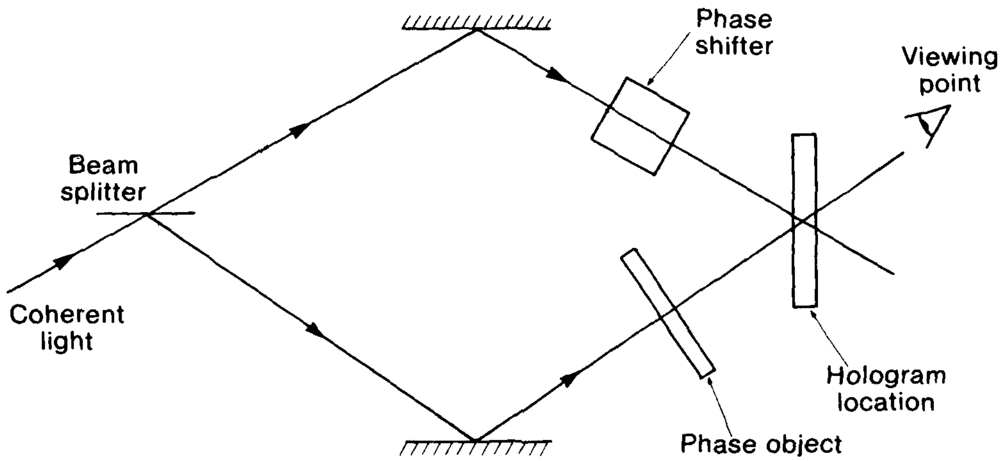


Fig.7 Holographic subtraction

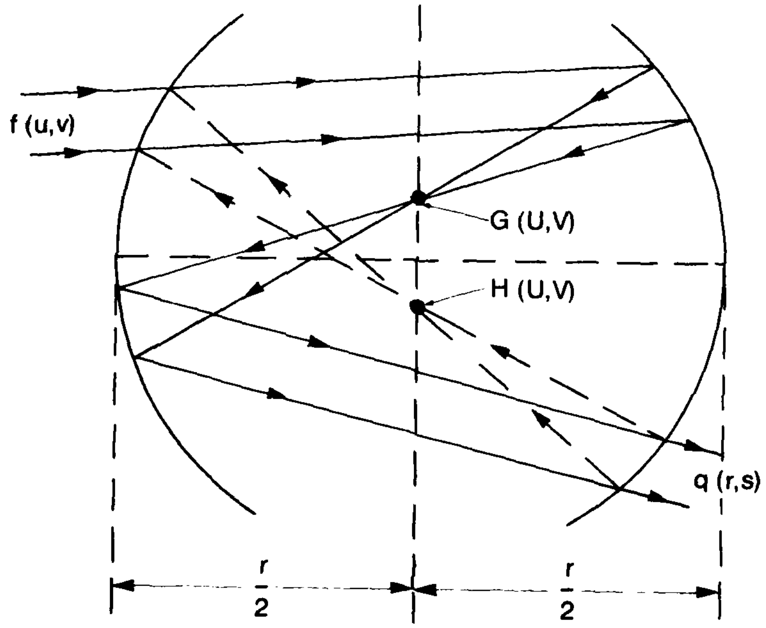


Fig.8 Coherent optical processor with feedback

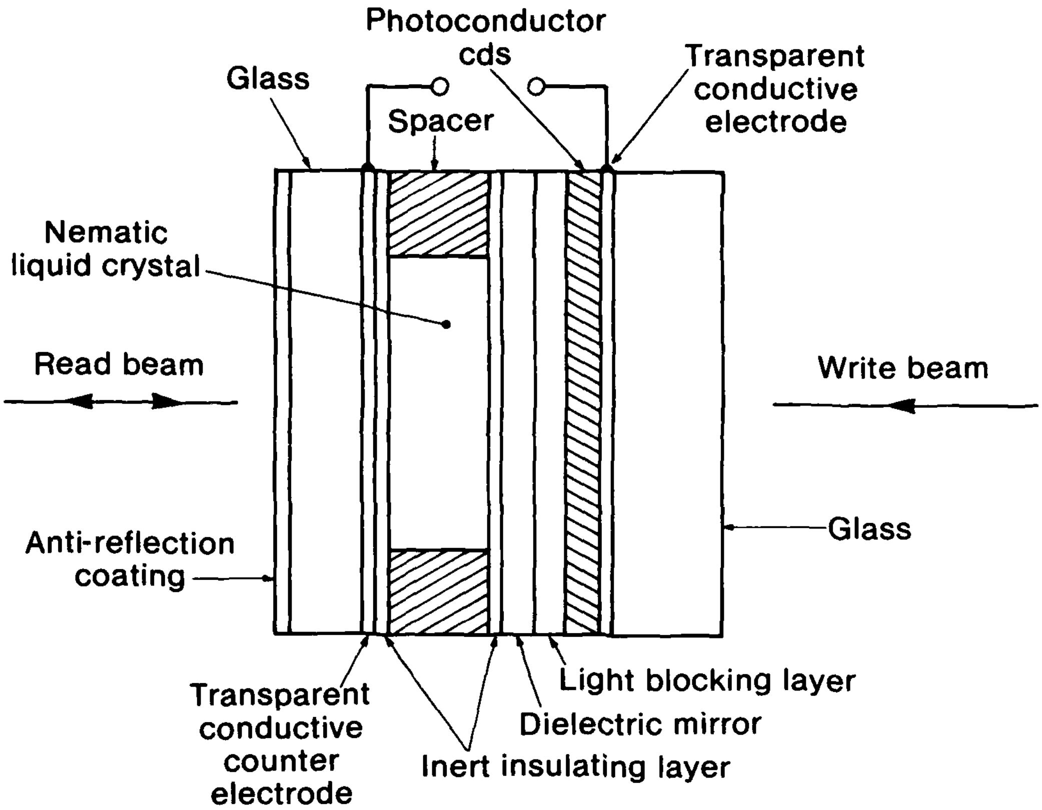


Fig.9 Hughes liquid crystal light valve

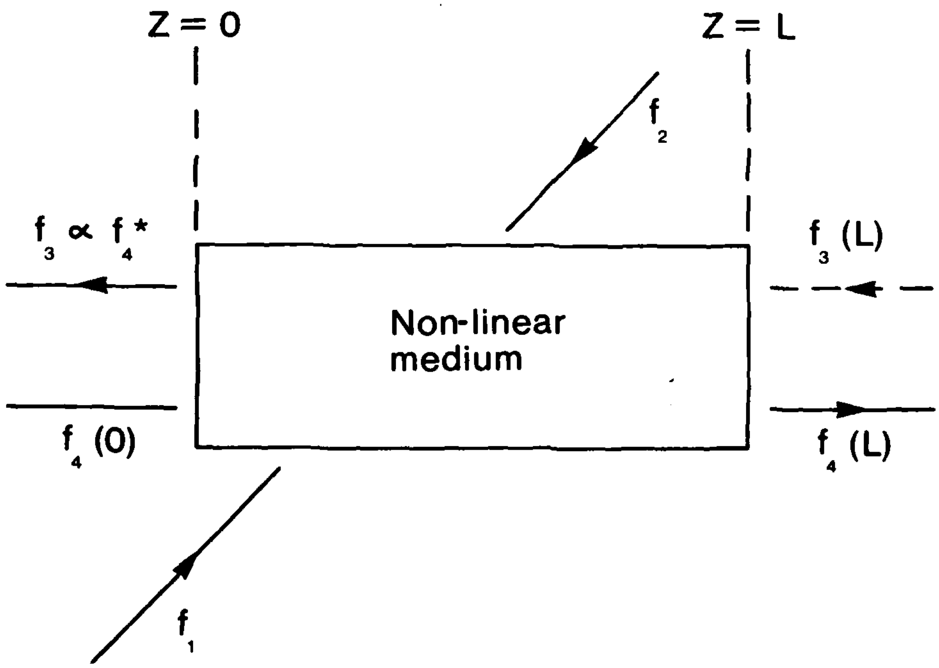


Fig.10 Four-wave non-linear optical mixing

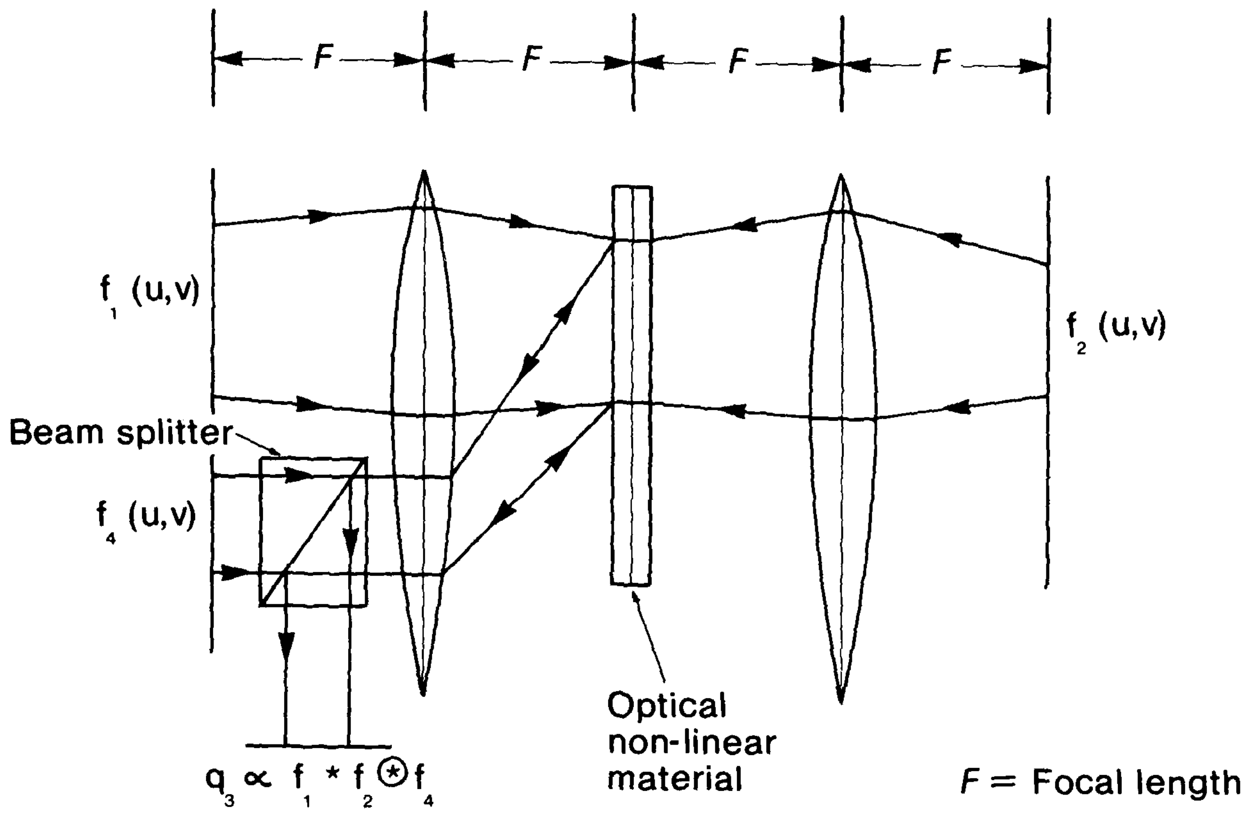


Fig. 11 Phase conjugate optical processor

A PLANNING SYSTEM FOR F-16 AIR-TO-SURFACE MISSIONS

by

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1. INTRODUCTION

The F-16 aircraft is recently introduced in the Royal Netherlands Air Force (RNLAF) to be employed in both the air-to-air and air-to-surface role. The F-16 is optimized for single pilot operation and has an integrated, highly automated avionic system.

Successful air-to-surface mission accomplishment is highly dependent on the avionic system capabilities as navigation, target acquisition, fire control and weapon delivery. To make use of the full avionic potential the set-up of its subsystems needs careful planning and preflight preparation. Also for navigation and in-flight system operation detailed information and checklists have to be prepared.

In this paper a concept for a mission planning system is presented which provides the F-16 pilot with a tool to perform adequate preparation.
Therefore first the specific F-16 avionic demands on mission planning are summarized. Next two systems related to mission planning are described as they are presently under development by the National Aerospace Laboratory (NLR) in close cooperation with the RNLAF. Finally special attention is given to the assembly of the F-16 in-flight essentials into a combat mission folder.

2. F-16 AVIONIC DEMANDS ON MISSION PLANNING

2.1 F-16 air-to-surface avionics

In the air-to-surface role the F-16 can deliver a variety of weapons. An integrated fire control avionic systems provides for that purpose the capabilities to locate, acquire and attack air-to-surface targets. Its subsystems include weapon delivery related avionics and mission related avionics.
The weapon delivery related avionics provide for store handling, navigation, target identification and display of related data (Fig. 1). Critical combat controls and switches are located on the throttle grip and side stick to allow quick reaction, fingertip control of weapons, radar and displays.
Mission related avionics provide for various penetration aids including Electronic Counter Measures (ECM), threat warning and chaff/flare dispensing (Fig. 2).

F-16 avionic system operation makes specific demands on mission planning (1). In the following paragraphs each subsystem is discussed individually as far its preflight set-up or in-flight use need special planning consideration and preparation.

2.2 Inertial Navigation Set (INS)

The INS is the prime source for navigation information. It provides the Fire Control Computer (FCC) continuously with information about the present position in terms of geodetic latitude, longitude and system altitude. The FCC then provides range and steering information to one of the 10 selectable destinations or to one of two selectable Offset Aim Points (OAPs) associated with each of the destinations. Each destination may represent a waypoint, initial point, target etc. and is stored by its geodetic latitude, longitude and elevation. The OAPs are stored in terms of true bearing, range and elevation. Since the number of destinations is limited careful selection of waypoints during mission planning is required.
The Fire Control Navigation Panel (FCNP) is the pilot's interface with the INS and FCC. Mission planning should provide a FCNP programming menue containing all the data to be entered. As the F-16 does not have a projected map display there is a need for navigation maps. Annotated along the route these maps should contain cues such as waypoint coordinates, distance marks, time ticks etc. to monitor and cross check proper INS operation in flight.

2.3 Stores Management Subsystem (SMS)

The SMS is the primary interface between the pilot and the weapon suspension system. When the SMS is programmed to match mission requirements it provides for: store inventory loading, in-flight weapon monitoring and control, weapon delivery mode selection, storage of weapon parameters including burst altitude, arming delay, function delay etc. The SMS passes this information to the Fire Control Computer (FCC) for proper weapon release computation.
The SMS gives the pilot the opportunity to store during mission preparation several delivery options called attack profiles and arrange them in such a way that by using a simple step-through method he can change to the option best suitable for the tactical situation, even during attack. In order to cope with unknown factors as change in weather, threats encountered, range at which the target is acquired and system failures, the set-up and arrangements of the attack profiles need careful selection during planning. Even with a computing delivery system the pilot has to consider the delivery parameters to assure fuze arming and fragmentation clearance. Preparing the set-up of the SMS (SMS planning table) is therefore an essential part of mission planning.

2.4 Fire Control Computer (FCC)

The FCC is a general purpose digital computer that implements an Operational Flight Program (OFP) for weapon delivery and navigation computations. In order to perform this function the FCC is integrated with the Inertial Navigation Set (INS) and Stores Management Subsystem (SMS) by means of a digital data multiplex bus.
In addition the FCC provides energy management by presenting cues to optimize the flight profile for range, endurance or combat. It also gives warnings on its computed remaining fuel. These energy management

computations are partially based on SMS inventory of loaded stores but need additional preflight inputs via the Fire Control Navigation Panel (FCNP). The FCNP programming menue should contain therefore figures as bingo fuel and home steering point.

2.5 Radar system

The F-16 radar is a digital multiple mode, pulse doppler radar. In air-to-surface operations it provides on the radar display a ground map for navigation, fixtaking and weapon delivery especially for conditions of reduced visibility.
The pilot has the option to select several radar modes. The so-called Doppler Beam Sharpening (DBS) mode is used especially during low level navigation for fixtaking and aiming. DBS improves radar resolution for objects which are more than 15 degrees out of the aircraft velocity vector. Unless such an object has a significant radar signature, radar predictions for all positions which are planned to be used for aiming or fixtaking are required.

2.6 Electronic Counter Measures (ECM)

ECM procedures and tactics based on the latest intelligence information and the flying unit's doctrine are to be considered at mission planning. These considerations should include the use of ECM-pods, chaff/flare dispensers and threat warning system.
Tactics for ECM dictate normally different system switch settings for the different phases of the mission. The navigation maps should therefore contain annotations and checklists at positions where those settings are to be changed.

3. AIR-TO-SURFACE MISSION PLANNING

3.1 General

Mission planning in general is the detailed preparation by the aircrew for all aspects of a mission prior to its execution.
Planning of an air-to-surface mission should incorporate all the available intelligence, navigation, meteo and weapon data in order to assure the maximum chance on mission success.
Dependent on the type of mission and formation size the time allowed for mission preparation varies from 20 minutes to several hours. Within this limited time, preparation of the preflight and in-flight material for navigation and system operation is an essential part of mission planning.

3.2 Mission planning activities

The pilot planning procedures can be divided into three main activities: the collection of information to prepare the allocated mission, the study and processing of this information into appropriate route and tactics and the plotting of navigational maps and production of other mission materials. To indicate the amount of work these activities are described next in more detail.
The planning information incorporates:

- air task data : target and alternate targets
  times and control data
  number of aircraft and armament
- intelligence data : detailed target information
  enemy defences and position of own troops
  communication and identification procedures
- navigation data : aeronautical charts
  routing restrictions
  prepared common routes
  terrain and obstacle data
  radar predictions
- meteo data : weather at home base and diversions
  expected weather for enroute and target area
- aircraft and weapon manuals.

The study and processing of this information take place in two phases:

- target area planning: selection of run-in and escape
  selection of attack and delivery techniques
  determination of heading, ranges and times
- enroute planning : selection of route and waypoints
  choice of route profile (speeds and altitudes)
  selection of tactics, use of counter measures etc.
  determination of navigation parameters as headings, times, distances, fuel, etc.
  insertion of standard procedures for loiter and recovery
  calculation of take-off and landing data.

The output of the planning process should contain:

- detailed 1:50.000 scale target run-in map and the overall 1:500.000 scale enroute maps; on the maps for each mission leg all the relevant data as collected or calculated are plotted
- navigational datalist to set up the navigation system
- settings and delivery parameters to set up the weapon system
- data about force allocation, communication and control
- flight plan, only in peace time, for air traffic control.

4. A CONCEPT FOR A MISSION PLANNING SYSTEM

4.1 System requirements

The pilot procedures in preparing air-to-surface missions have been analyzed extensively (2,3). From these studies the following key requirements have been derived for a computerized system for mission planning at airbase level:

- the experience of pilots and other specialists involved in mission planning must directly be used in the planning process;
- the up-to-date information which is essential for mission planning must be made available at request in an easily accessible form, i.e. in many cases graphical information in relation to the planning map;

- the calculation of the navigational data, weapon parameters and aircraft performance data must require only minimal control and effort by the pilot;
- the planning results, navigation maps and additional information must be combined in a combat mission folder; checklists for preflight set-up and in-flight operation of aircraft subsystems must be prepared;
- an immediate access is required to the results of earlier planning activities e.g. prepared or preplanned missions;
- the accuracy of the automated planning process must at least be equal to the accuracy of the traditional planning on standard maps as far as positioning is concerned.

In addition to these operational requirements the following organizational requirements must be fulfilled:
- to use the planning systems only minimal system background knowledge must be required from the pilot;
- in first instance the system must allow mission planning in such a way that the automated process is very similar to the existing manual method;
- it must be possible to use the system as a basis for further evolutionary development when experiences are gained with computerized planning and integration of other automatic means in the mission preparation procedures;
- the costs in the phase under consideration should be minimal as well as the costs related to further evolutionary development if required; this includes in most cases the use of commercial available hardware and software elements;
- for final use in an operational environment the planning system should meet general requirements concerning system redundancy, survivability and security.

4.2 Technical concept of the planning system

The requirements of the planning system are in principle similar to the requirements underlying Computer Aided Design (CAD) systems. For these systems it is essential that the user can optimize the desired result with regard to a number of mostly conflicting demands. This is realized step by step in an interactive communication between the user and the system (4).
In the present case this dialogue has to be such that the planner can continue to think in mission profiles on a planning map, threats indicated on this map and so on. Next to this the planner wants to be able to obtain numerical information related to the mission (5).
The technical concept for the mission planning system contains therefore the following elements (Fig. 3):
- a computer for automatic data processing and application of mathematical models with a background memory for storage of the programs and fast entrance to the planning data;
- a workstation consisting of:
  . a graphical display for interactive control of the planning process; on this display an electronic map is presented together with the planning data and the results of the planning activities;
  . an alphanumerical display for input and presentation of information and planning results;
  . a digitizer suitable for standard planning maps and for accurate input of position data in a way simular to the existing planning;
  . a printer for output of planning data.

5. MISSION PLANNING SYSTEMS IN THE NETHERLANDS

5.1 Introduction

The RNLAF has since 1973 and in cooperation with the NLR since 1975, carried out several studies and projects in order to support by means of computer facilities its war tasks related activities. From the beginning these efforts were focussed on:
- the improvement and speeding-up of the information processing during the detailed pilot mission planning,
- the automation of the traditional information facilities (telephone, telex, mobilophone, radio and planning boards) providing the data for all processes directly related to mission preparation and execution.

To illustrate the system concept as given in chapter 4 two systems related to mission preparation will be shortly described as they are presently under development by the RNLAF and NLR: the system called Computer Aided Mission Preparation at Airbase Level and the Operational Management and Information System.

5.2 Computer Aided Mission Preparation at Airbase Level (CAMPAL)

An interim configuration of CAMPAL was provided during the F-16 Multinational Operational Test and Evaluation operations conducted from Leeuwarden AB in 1980.
This interim program featured interactive use of a remote mainframe computer by means of a teletype terminal. It supported mission planning by translating the pilot's basic routing and attack plan into the data for the navigation system set-up and for composition of the F-16 combat mission folder.
The program demonstrated the required accuracy of the navigational and aircraft performance calculations and the usefulness of the program printouts (6).

A CAMPAL-system in accordance with the technical concept as described in chapter 4 is recently installed at Leeuwarden AB where the first F-16 squadron became operational in April 1981. In first instance the work-station at the squadron navigation section (Fig. 4) is connected via a multiplexer and dedicated telephone line to a remote mainframe computer. There are provisions to add later on online plotting facilities or elements to produce hardcopies of the information as presented on the graphical display.
To minimize the programming effort on the mainframe computer use is made of a database management system and a tutorial command language system. These elements were available from other CAD-applications.

5.3 The Operational Management and Information System (OMIS)

From organizational point of view a challenge is to realize and introduce an appropriate data gathering system at airbase level from which the up-to-date information can be obtained that is essential for the planning process (air task, intelligence data, meteo data etc.). This problem is being solved in The Netherlands in a different project which has to result in an information system at airbase level to support all processes in preparation and deployment of aircraft (7).
The main hardware of this system called Operational Management and Information System (OMIS) consists of interconnected mini-computers for information processing, online discs for information storage, alphanumeric displays for information retrieval and update, and printers (Fig. 5). An OMIS-pilot system is installed at the moment at Volkel AB.

6. F-16 COMBAT MISSION FOLDER (CMF)

In general a CMF is intended for in-flight use during an air-to-surface mission. It has to be composed during mission planning and contains in an easily accessible, well organized manner all the material required for navigation and system operation. The size, contents and layout of a CMF is greatly influenced by the weapon system in use.
The F-16 is designed for single pilot operation. The so-called hand-on-control concept gives the pilot the ability to make all necessary selections during attack and other critical phases without having to release the throttle or side stick. This concept prohibits the use of hand held maps or other loose paper work in the cockpit. Due to the limited cockpit space the only place to hold and display maps and other in-flight information seems to be the pilot upper legs. Therefore a relatively small booklet-type folder (9 cm x 25 cm) has been designed which can be attached by velcro strips on the g-suit left or right leg (Fig. 6).
Reference 8 contains guidance on the contents, format and compilation of F-16 CMFs. It covers the agreement reached by the F-16 user nations of the Central Region Air Forces and reflects the recommendations made by the pilots and planning sections of the F-16 Multinational Operational Test and Evaluation program. According to this document the F-16 CMF has to be composed of the following items:
- launch data card,
- overall mission portrayal map,
- navigation strip charts,
- leg information sheets,
- departure and recovery procedures,
- navigation system set-up (FCNP-menue),
- stores management set-up (SMS planning table).

The enroute maps covering the intended route make up the main part of the folder. They are inserted in sequential order as right pages (Fig. 7). The planned route is annotated on the map strips by depicting the waypoints including the courseline with time and distance marks. Also off-track checkpoints and positions where operational actions are required will be annotated.
Additional advisory information in the form of checklists etc. are, to prevent map clutter, put together with the navigation information (arrow box, nav info box) on a separate sheet which is inserted as the left page opposite to the associated map strip. Annotations about the current situation like enemy order of battle and airspace restrictions if required, are made directly on the map strips or on transparant overlays.

7. POINTS OF CONTACT

Those who like to have more information on the systems described are advised to contact one of the following points:

- Royal Netherlands Air Force (RNLAF)
  Assistent Chief of Staff for Operational Requirements (AOB)
  Section Operations Research and Evaluation (ORE)
  Prins Clauslaan 8
  2595 AJ The Hague, The Netherlands
- National Aerospace Laboratory (NLR)
  Informatics Division (I) or Flight Division (V)
  Anthony Fokkerweg 2
  1059 CM Amsterdam, The Netherlands.

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(2) STAHLIE, T.J., June 1975, "Preparatory study on the desirability and possibilities to use computer facilities during the preparation of operational RNLAF-missions (in Dutch)", NLR TR 75082 C (secret).
(3) BOSCH, F.J., van den, et al., Dec. 1980, "Functional analysis of mission preparation and preliminary design of the evolutionary CAMPAL-system (in Dutch)", NLR TR 80056 C (confidential).
(4) LOEVE, W., 1979, "Managements aspects in Computer Aided Design (in Dutch)", Informatie 1979 vol. 21(11) pp. 647-716.
(5) ANDERSON, R.H., SHAPIRO, N.Z., Febr. 1979, "Design considerations for computer-based, interactive map display systems", Rand No. R-2382-ARPA (unclassified).
(6) Anon., May 1981, "F-16 MOT&E Final Report on operational effictiveness", TAC Project 77AT-092F, (secret).
(7) BOSCH, F.J., van den, et al., Nov. 1976, "Preliminary design of the operational management and information system (in Dutch)", NLR TR 76079 C (confidential).
(8) Anon., May 1981, "Preparation of F-16 Combat mission Folders (unclassified), F-16 MOT&E Final Report, App. I of Annex A TAC Project 77AT-092F.

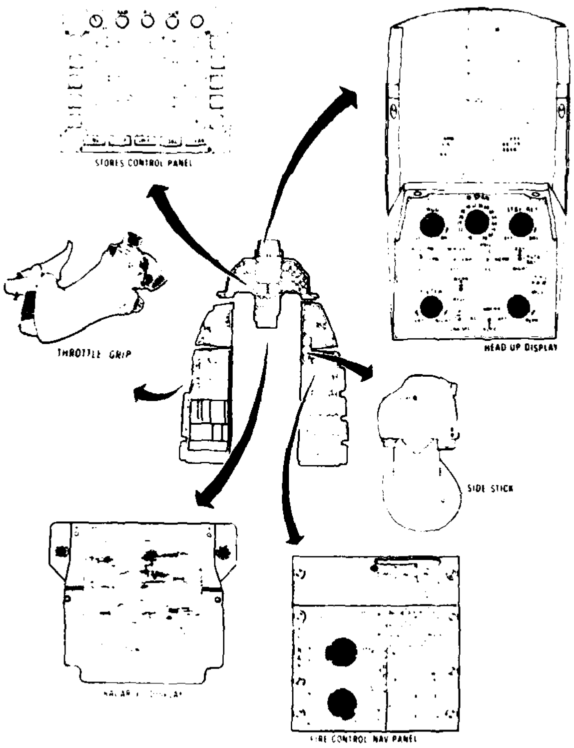

Fig. 1 F-16 weapon delivery related avionics

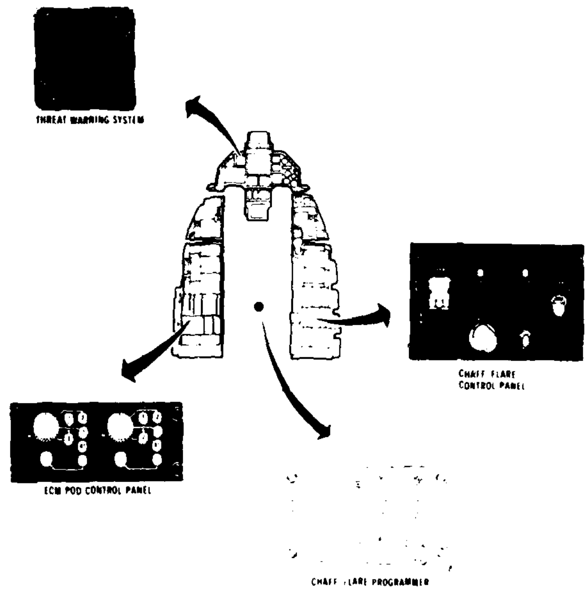

Fig. 2 F-16 mission related avionics

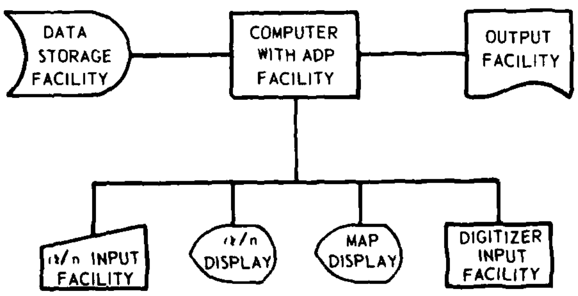

Fig. 3 Technical concept of a mission planning system

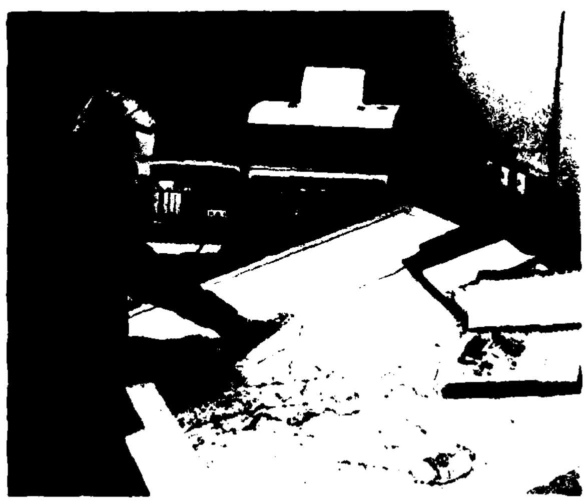

Fig. 4 CAMPAL workstation

Fig. 5 OMIS workstation

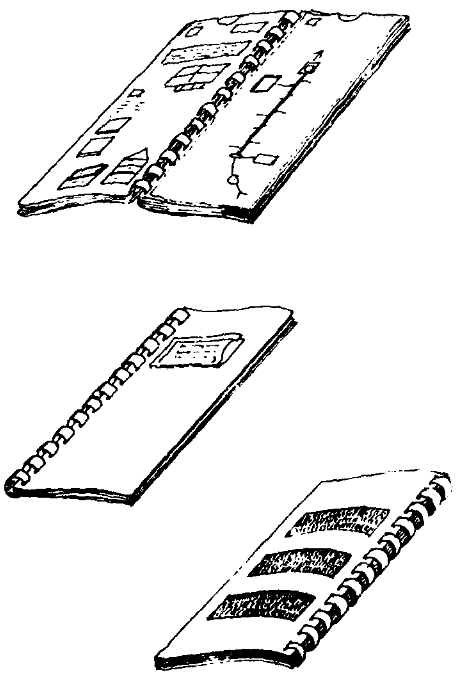

Fig. 6 Lay-out of F-16 CMF

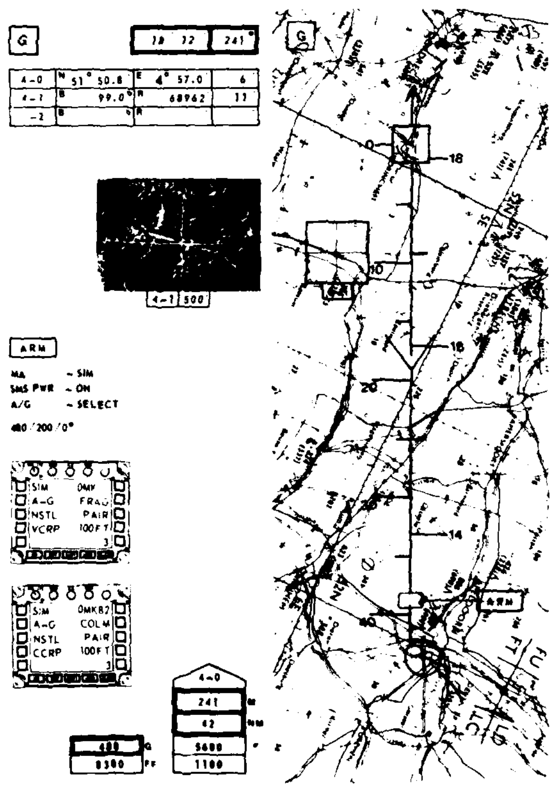

Fig. 7 Example of F-16 CMF-pages
(original 9 cm x 25 cm in colour)

PAVE MOVER AIDED INTEGRATED STRIKE AVIONICS SYSTEM

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SUMMARY

Hughes has been exploring system integration concepts for ground attack aircraft which incorporate emerging, advanced avionics. The primary impact of the new avionics is to permit a higher level of automation in attack aircraft, and the primary problem in systems integration is to implement the automation in a manner compatible with mission requirements and acceptable to the pilot weapon system operator. This paper briefly describes the integration approach which resulted from the Integrated Strike Avionics System (ISAS) Study (DuPuis and Mendez, 1980), and then the paper discusses the performance enhancement which results from augmenting the ISAS attack aircraft (i.e., an aircraft whose advanced avionics are integrated in the manner of ISAS) with real time targeting data gathered from a stand off surveillance/reconnaissance system typified by the Pave Mover radar (DuPuis and Mendez, 1981).

1.0 INTRODUCTION

The dominant trends in modern attack aircraft are (1) low altitude operations for enhanced survivability and (2) multiple release per pass of precision-guided munitions for enhanced fire power. The low altitude operations have the effect of shortening ranges to targets at unmask and severely limiting the time available to acquire targets, classify and prioritize them, initialize the precision-guided munitions (Maverick, for example) for surgical strike, convert to attack, release the weapons and perform a breakaway maneuver. The short ranges and timelines drive the requirement for advanced avionics and their automation. Figure 1 depicts a typical weapon delivery profile and its associated time and range compressions which represent the technical problems driving the intelligent integration of the advanced avionics (automatic target recognition and hand off systems in particular).

The highest payoff for this kind of attack obtains when (1) the highest priority is assigned to air defenses among all targets and (2) the targeting to (multiple) weapon release sequence, measured from unmask, is managed in an extremely short elapsed time in order to outperform the air defenses.

In order to satisfy both conditions, a probability of target classification well above 90% (and possibly 95%) is required. This is not tenable in short timelines and reasonable attack ranges with single targeting sensors, even with automatic target recognizers. Hence, the integration of advanced avionics must address this issue.

2.0 TECHNICAL APPROACH

A methodology has been developed to derive technical requirements for fire control systems consistent with the low altitude tactics. The methodology establishes targeting sensor demand curves that are functions of the aircraft speed, weapon release constraints, and distance of the nearest approach to the target (i.e., disengage and escape maneuvers are included). The demand curves specify targeting sensor range performance based on satisfying the fire control requirements. Very often, single sensors are unable to satisfy the demand curves so that a solution based on multisensor correlation must be explored, together with decision logic, decision criteria and terminal logic (i.e., means of performing forced decisions when the decision criteria are not met and time/range closure allowances are exceeded).

The solution takes the form of a battle management function which fuses inputs from uncorrelated targeting sensors and produces target tracks and priorities for the fire control computer (see Figure 2). An attack aircraft with such a battle management function integrating the outputs of diverse automated sensors is said to be an ISAS aircraft.

To illustrate the improved target classification due to multisensor correlation, two sensors and their corresponding performances were postulated: a MMW radar (R), and a FLIR (F). Their respective classification performances versus a hypothetical target, as a function of range, are shown in Figure 3 for 0.85 and 0.75/km atmospheric IR transmittance. Under these conditions, the MMW radar sees clear atmosphere. The figure shows the MMW radar having a relatively low confidence of classification (because of target signature ambiguities), hence, a flat classification performance curve at about P_{class}=70 per cent, independent of range (over the range increment shown).

Means of combining target declarations (including their confidence) were investigated and applied to target declarations from the single sensors (as defined by Figure 3). The logic required that the confidence exceed a specified threshold confidence (90 per cent even if the individual probabilities of classification were lower). Figure 4 shows the Monte Carlo probability of correct decision results of single (R,F) and dual sensors (RF) in two weather conditions.

In all cases investigated, a particular probability of correct decision is always obtained at a longer range with dual sensors and multisensor correlation than with single sensors. Hence, multisensor correlation is simultaneously a means of obtaining correct target decisions more quickly and obtaining range punchthrough. It is, therefore, a critical ingredient in solving the targeting problem of advanced attack aircraft.

The use of multi-sensor correlation presupposes that the battle management function can warp and register the various sensor outputs, so that targets and target tracks can be associated.

3.0 ISAS EFFECTIVENESS ANALYSIS

Three system configurations were intercompared by the technique of map modeling. The map modeling "flies" a representation of the avionics along a flight profile over some land mass data base. A deployment of the enemy forces will have been represented on the land mass also. The attack aircraft and enemy forces interact in a manner determined by their representations. The range performance, angular coverage, time delays and weapon effectiveness are critical elements of the representation. The map modeling allows the measures of expected kills by the attack aircraft and its survivability, as well as their correlation, to be readily determined.

The three system configurations which were intercompared by means of map modeling were: (1) a Baseline (single automated targeting sensor), (2) ISAS (multi-sensors, automated and correlated), and (3) multi-sensors (without automation and correlation).

The results of the map modeling indicate that ISAS significantly outperforms the Baseline, but that multiple targeting sensors without automation perform less well than the Baseline. Thus, the performance improvement of an ISAS aircraft resides in its automation and correlation (i.e., integration) and not in its multiplicity of sensors.

4.0 REQUIREMENT FOR PAVE MOVER AIDING

Drifts in the navigation system and movement of the assigned target complex present serious problems to the attack aircraft. If the attack aircraft remains low, then its engagement with the target complex may be a sudden encounter for which it cannot properly convert to attack. If the attack aircraft pops up to take out its targeting uncertainties and get a fix on the assigned targets, then its survivability is risked.

To solve these problems, the attack aircraft requires the assistance of an external system which keeps track of the targets and of the attack aircraft and, in essence, performs traffic control for the engagements. An external system with these faculties is the stand off surveillance/reconnaissance radar known as Pave Mover.

This paper will not describe the technical aspects of Pave Mover, but will describe the usage and advantages of such a system to attack aircraft.

5.0 USAGE OF PAVE MOVER INFORMATION

Information which can be provided by Pave Mover to the attack aircraft includes (1) location of air defense threats (generated by overlaying Pave Mover and tactical emitter locator data), (2) target number densities to preset the ISAS a priori terms in the multi-sensor correlation algorithms, and (3) relative location between the attack aircraft and the target complex assigned to the attack aircraft. All these kinds of information can be readily conveyed to the man/machine by means of simple interfaces with the ISAS battle management functions, as shown in Figure 5. The corresponding interfaces for a non ISAS ("minimum modification") aircraft are shown in Figure 6.

It should be clear how the first two categories of Pave Mover information can be used, respectively, to (1) select routes of maximum survivability and (2) enhance the ability to perform surgical strikes against the high combat capability targets of the target complex assigned to the attack aircraft. It is not so clear how the third category of Pave Mover information can be used to optimize expected kills by and survivability of the attack aircraft. Hence, the remainder of the paper will dwell on this aspect of Pave Mover aiding.

6.0 PAVE MOVER AIDED ISAS

Pave Mover information was used to direct the attack aircraft in the following manner. The coordinates of targets (especially air defenses) which were detected by Pave Mover and which were in the assigned target complex were used to derive a linear fit by the method of least squares. Pave Mover inputs (via data link) were used to direct the attack aircraft to a point where it could perform a controlled unmask in order to engage the target complex.

Various engagement geometries are possible, but in this preliminary analysis, only flyovers were studied. The intent was to study the advantages of minimizing search and conversion to attack by use of Pave Mover information and directions. Of course, an attack aircraft prepared without advanced avionics, or automation for that matter, could also receive Pave Mover information and directions. So, it was of particular interest to determine the advantage of Pave Mover to a Baseline as compared to an attack aircraft with integrated, advanced avionics.

7.0 EFFECTIVENESS ANALYSIS OF PAVE MOVER AIDING

Map modeling was used to compare Baseline with ISAS performance when either was directed to and in a strike zone by Pave Mover. The results with the Baseline indicated that more targets unfold in the flight path directed by Pave Mover than the Baseline aircraft is capable of acquiring, classifying and attacking. Thus,

a Baseline's expected kills performance is not necessarily enhanced by Pave Mover. Also, its survivability is decreased by virtue of being embedded in a high target density environment.

On the other hand, ISAS, with its automation and advanced avionics, is able to quickly acquire, classify, prioritize and attack all targets which unfold in the Pave Mover directed flight path. This ability allows ISAS to pre-empt the air defenses and to increase its expected kills and survivability, simultaneously.

Thus, Pave Mover and ISAS are complementary in that ISAS can respond correctly in engagements to which Pave Mover directs it. A Baseline attack aircraft has been found to saturate in these engagements if it must perform surgical strikes with lock on before launch type of weapons.

8.0 SENSITIVITY TO PAVE MOVER INFORMATION QUALITY

The map modeling evaluation of Pave Mover aided ISAS was carried out with a parametric variation of the Pave Mover information quality. The cases studied included (1) missed target detections, (2) all targets detected but their locations were "noisy" up to 0.75 km, and (3) combinations of (1) and (2).

The map modeling indicated that the ISAS and Baseline measures of effectiveness were very sensitive to missed detections and very tolerant for locational uncertainties (up to 0.75 km).

9.0 CONCLUSIONS

Advances in avionics for air to ground attack are driven primarily by the growing importance of low altitude tactics (for increased survivability) and multiple release per pass of precision-guided munitions (for increased fire power). The advanced technologies which make the new tactics tenable are those related to low altitude navigation, automatic recognition of targets, and automatic, precision hand-off to weapons.

We have developed methods for specifying targeting sensor performance, based on tactics and weapon characteristics alone. Targeting sensor specifications ("demand curves") developed in this manner indicate that, for quick reaction, surgical, short range attack with precision-guided munitions, single sensors do not generate sufficient confidence ("supply curves") to satisfy the required timelines. This problem is alleviated by treating all sensors as an integrated set -- the ISAS concept.

The new tactics produce sudden encounters which do not always yield a favorable attack geometry -- even if the ISAS is able to distinguish the high priority targets in its field of regard. This situation is greatly improved by real time targeting data from a stand off target acquisition/control system such as Pave Mover. Maximum benefit from the new tactics and weapon delivery concepts is accrued by the pairing of the complementary capabilities of ISAS and Pave Mover. The ISAS/Pave Mover combination optimizes the strike effectiveness and survivability of ground attack aircraft which must penetrate to the battlefield and deep interdiction regions.

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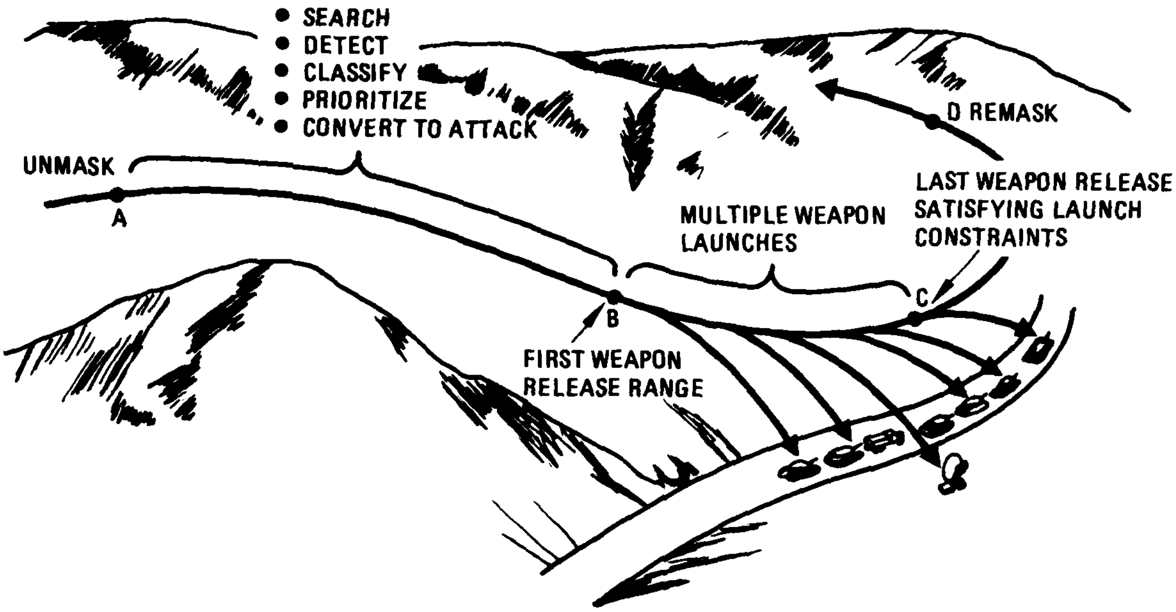

Figure 1. Timeline constraints on low-altitude, multiple launch profiles.

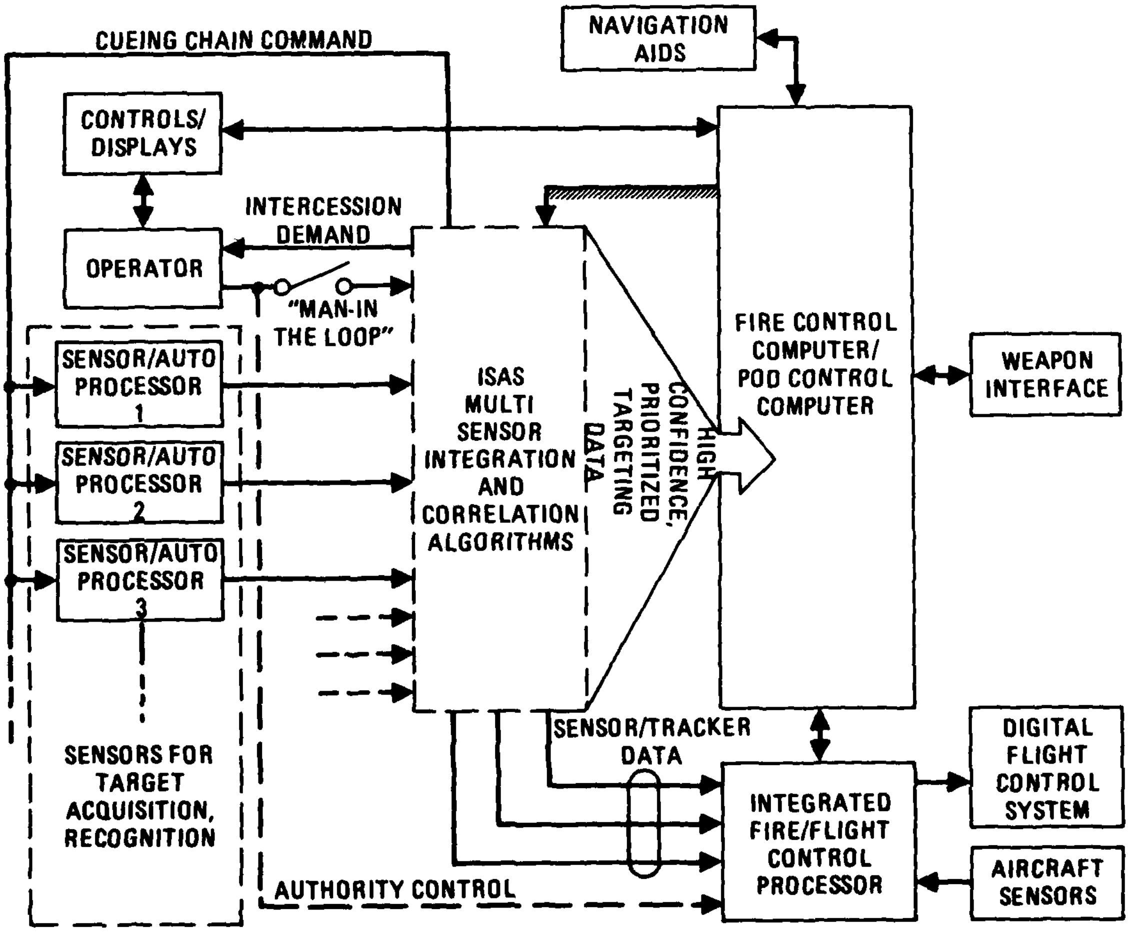

Figure 2. ISAS interface diagram.

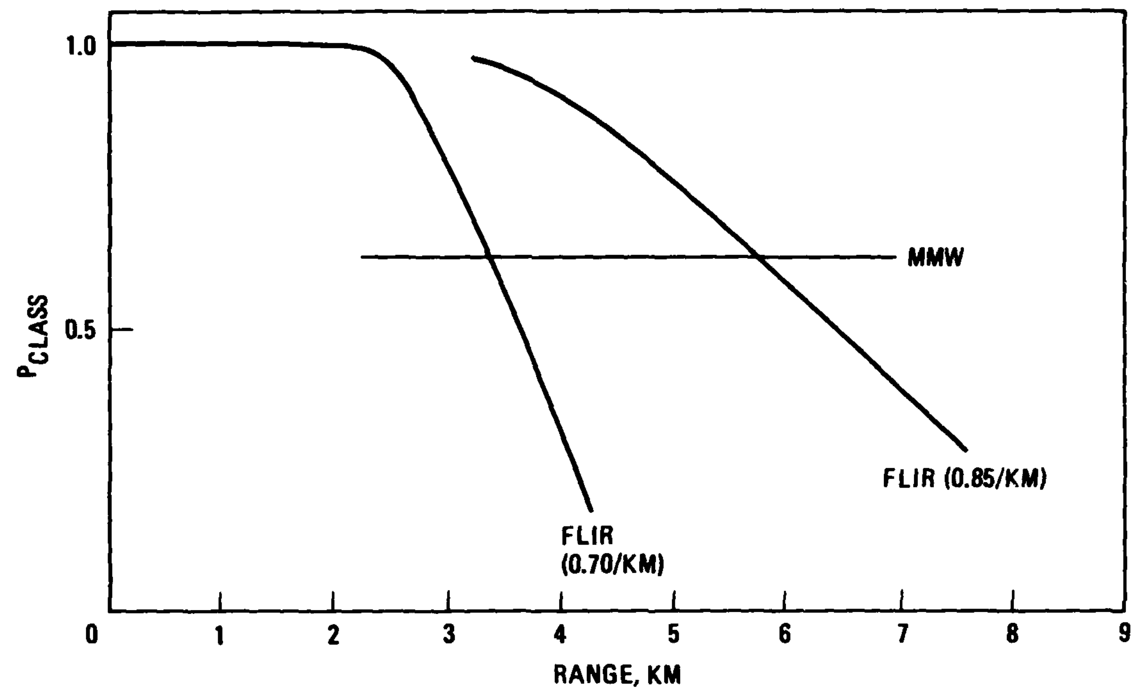

Figure 3. Postulated single sensor target classification capability.

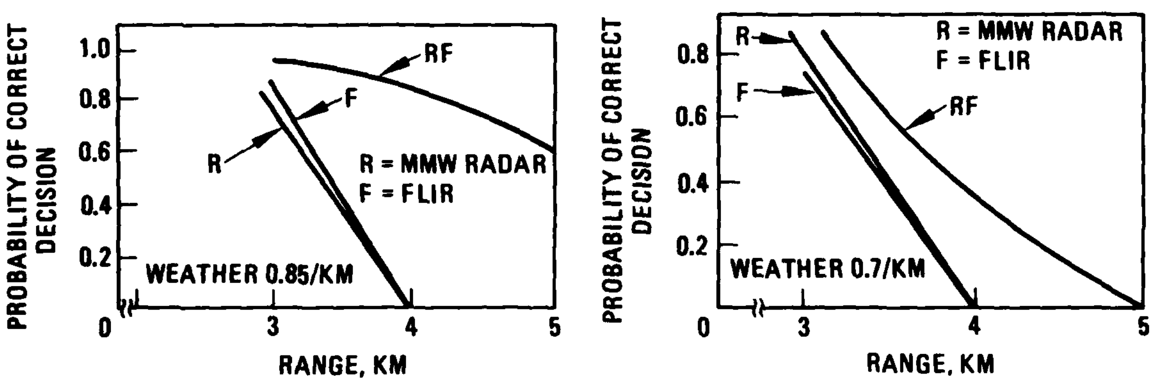

Figure 4. Typical results of probability of classification with and without multisensor correlation.

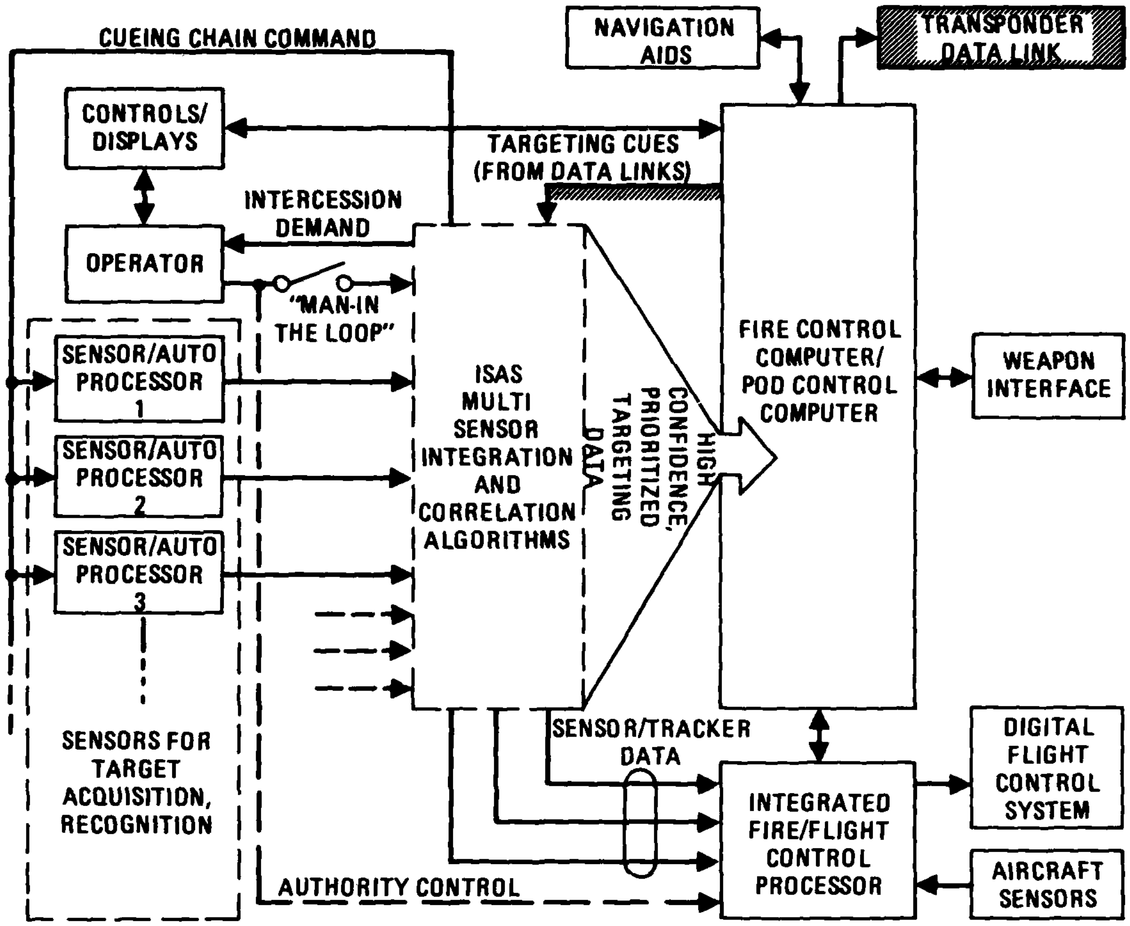

Figure 5. PAVE MOVER aided ISAS interface diagram.

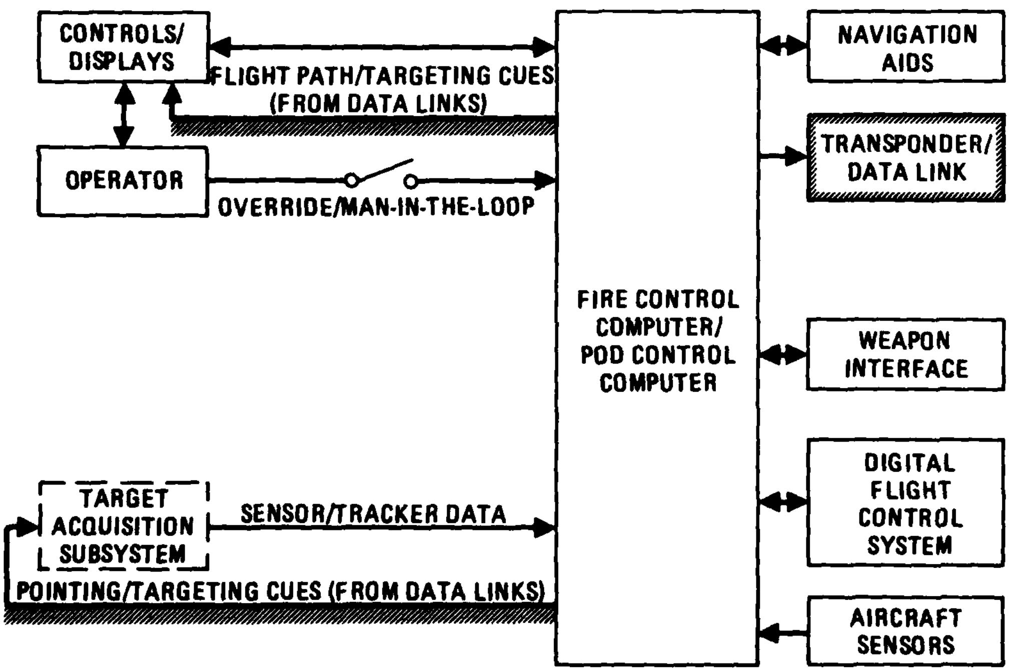

Figure 6. Minimum modification tactical aircraft/PAVE MOVER interface diagram.

ADAPTIVE MULTIFUNCTION SENSOR CONCEPT FOR AIR-GROUND MISSIONS

by

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1. INTRODUCTION

With the improved performance and diversity of future surface-to-air defence systems it is apparent that new tactics and techniques will have to be developed, and existing ones improved, in order to increase the probability of success of the interdiction mission (Crawford N., 1977). These methods can be divided into two categories. Firstly, those that reduce the probability of detection of the aircraft by the defensive radar network e.g. reduction of aircraft cross-section, the use of stand-off weapons and of low-level flight where the aircraft attempts to fly beneath the radar coverage. The second category is that which denies to the enemy the opportunity of obtaining a fix on the interceptor using signals emanating from the aircraft. Such techniques include the use of bistatic radar and of Dim methods where the transmitter power is reduced during some sections of the flight. Radiation management and Electronic Countermeasures (ECM) also play an important role in this context.

This report is primarily concerned with the requirements imposed on a radar system if it is to be installed in aircraft flying low-level interdiction missions.

A typical low-level air-ground attack scenario will be described together with the various radar techniques and modes that have to be employed. This leads to a discussion of the requirements on a nose radar and especially its antenna and how the radar must be integrated with the other aircraft sensors to form an adaptive multisensor system.

Finally, the ways in which a multisensor arrangement can reduce the pilot workload are considered-of vital important in a future strike aircraft.

2. A LOW-LEVEL ATTACK SCENARIO

A possible scenario for a low-level interdiction mission is shown in Fig. 1. The aim of the mission is to navigate the aircraft to a fixed point target which may lie from sixty up to several hundred kilometers behind enemy lines, accurately attack the target and return safely to base. In combat the mission must be performed in a hostile environment. The avionic system must be able to defend the interdictor against surface-to-air missiles (SAMs)and enemy interceptor aircraft whilst operating in the presence of electro-magnetic interference from both friendly and unfriendly sources. This implies that we must assume that, after take-off, the pilot can expect little or no assistance from the ground and must be able to attain, detect and attack his primary target and/or targets of opportunity independently. It is also required that the mission be flown at night and in all weathers which, in the conditions prevailing in the European Theatre, could severely limit the effectiveness of electro-optical sensors and degrade radar performance.

As can be seen from Fig. 1. the mission can be broken down into several distinct phases such as cruise, let-down, low-level ingress, target attack and low level egress each with its own problems and requirements. Navigation by means of the Inertial Navigation System (INS) (Kuperman G.G.,et al 1980; Robirette G.J., et al, 1981) with regular updates from the nose radar using High Resolution Techniques is of major importance throughout the entire mission while, in order to fly safely over long distances at low level, terrain avoidance or terrain following techniques must be used (Woodward A.C., 1979, Wheeler E.R., et al 1977).

The most difficult phase of the mission for the pilot is the attack itself where target detection and tracking and weapon delivery are the main priorities. To illustrate the difficulties: for an interdictor flying at a clearence height of approximately 30 metres and a speed of Mach 1, the maximum time available between the detection of the ground target and the delivery of the weapons is of the order of 8 to 10 seconds assuming a ground angle of 3^{o}. Within this time the pilot, with the help of the aircraft sensors, i.e. INS, nose radar, laser, infrared and low level TV, must detect and positively identify the target as well as priming, aiming and delivering the weapon to the target.

In addition to the requirements outlined above it should be borne in mind that merely being able to fly at low altitude is not a defence against interceptor aircraft if they have a look-down/shoot down capability whereby the enemy can detect and attack the interdictor either head-on of from the rear even against ground clutter. Thus the radar must be able to perform its interdiction activities

while simultaneously carrying out air-to-air search and tracking operations for self-defence purposes.

3. RADAR AND OTHER SENSOR REQUIREMENTS

Having outlined the various phases and problems of the mission we are now able to show the requirements on the radar and the other sensors needed in order that the aircraft can perform its interdiction role.

3.1 Radar Requirements

The radar modes used during the different phases of the mission, summarized in Fig. 2, may be interleaved in a manner shown schematically in Fig. 3. In addition air-to-air search/track operations are necessary throughout the mission. The radar may also be required to provide missile illumination, be IFF compatible and be able to navigate using ground beacons.

When one considers that many of these modes must be carried out simultaneously and the volume of space that the antenna must cover it is clear that the employment of a phased array antenna with its ability to scan from one area of interest to another almost instantaneously and, if an active array is used, to produce simultaneous, independent miltiple beams would be a great benefit to the radar system in carrying out the various tasks.

The inclusion of a phased-array antenna in an airborne radar system has, of course, many implications on the radar design. A phased array antenna is much heavier than an equi alent aperture conventional antenna and, in addition, may require cooling because of the heat generated in the active components that it contains. The beam steering computer must also be incorporated in the radar with a weight and volume penalty.

We shall now consider typical operational requirements during the different modes of operation. These are listed in Fig. 4. When these requirements are seen as a whole together with the requirement for all weather and night flying the need for a coherent, monopulse. Pulse-doppler radar, probably in X-Band, with a phased-array antenna and a large, rapid processing/calculating capability is clear.

To demonstrate the need for a phased array antenna more clearly we can show the estimated required minimum information update rates of the different modes of the radar. With the radar and aircraft parameters shown in Fig. 5, the information update rates, frame times and dwell times of the various modes were calculated and are shown in Fig. 6.

From these tables it can be seen that the requirement for a fully automatic Terrain Following (TF) system, generating new flight commands every 0.5 seconds, would impose severe restrictions on the operation of the other modes if a single, conventional antenna were to be employed.

There are several possible solutions to this problem (assuming that all the modes are to be retained). Firstly the radar may be split into two with a transmitter, receiver and antenna dedicated to TF functions.

A second alternative is to adaptively vary the update rate of the TF system: for example, if, during the flight, the aircraft is flying over level terrain the radar may be able to provide a profile of the land for the radar's entire 20 km range. Thus the information rate could be relaxed to the order of 4 - 5 seconds with little or no degradation in safety standards. Over rough territory, however, the update rate will have to be maintained at 0.5 seconds. A further alternative is to utilize a phased or active array that is capable of simultaneously forming orthogonal beams one of which could be used exclusively for the terrain following task while the other is used for Ground Mapping or Air-Air search or whatever mode is required at the time.

This last method would seem to offer the best alternative, avoiding the need for duplication of equipment whilst giving the continuous Terrain Following coverage which is essential for aircraft safety and survival. We shall now examine the ways in which such an antenna could be made and the probable performance that could be obtained from it.

4. PHASED ARRAY ANTENNA FOR A MODERN INTERDICTOR AIRCRAFT

As we have seen above, the various radar modes place conflicting demands on the antenna. These can be met to some extent by a phased-array antenna, which also permits other system improvements not possible with mechanically scanned antennas. In particular the phased-array allows:

- Electronic Beam Shaping (e.g. Pencil Beam or Cosec ^{2})
- Beam Agility (Multiple, Sequential, Hard-Track)
- Variable Scan-Rate (Slow Scan-Rate over Known Targets)
- High Scan Rate
- Electronic Polarisation Switching.

The major advantage of the P.A. is its beam agility which allows instantaneous switching from one mode of operation to another.

The scanning speed of the antenna can be adjusted to suit the mode of operation e.g. from 100^{o}/sec. for long-range search modes up to $\sim 1000^{o}$/sec. for short-range modes. The point is that the scan rate is fixed by the required dwell time on the target and not by mechanical limitations in the antenna.

Notice that simultaneous, multibeam, operation requires a more complicated beam-forming network, such as a Butler network, with multiple outputs, than a simple phased array. The limitations of the phased-array antenna can be appreciated from the simplified diagram in Fig. 7. Here it will be seen that the antenna is made up of three major sub-systems: the aperture with its radiating elements, the phase shifters and the power feeder. The latter may also include a monopulse comparator. In order to achieve low sidelobes the feed must produce an accurate, weighted power division at its outputs. The phase shifter resolution together with the amplitude accuracy of the feed will set the sidelobe levels.

For X-Band arrays with about 80 cm diam. a phase shifter resolution of 3 - 5 Bits is required. Typical accuracy values achievable for constrained feeds in X-Band would be about 1.0 dB amplitude and 12^{o} phase accuracy. The resulting sidelobe levels also depend on the number of radiating elements and whether the antenna scans in 1 or 2 planes. One could typically expect a 25 - 35 dB level w.r.t. the main beam for the first sidelobe and a r.m.s. sidelobe level of 45 dB for an antenna scanning in 2 axes. Note that the gain falls and the beam width and side-lobe levels increase as the antenna is scanned away from the boresight: for an 80 cm. aperture, X-band antenna one would expect a deterioration from 3^{o} to 5^{o} when the beam is scanned from boresight to $\pm 50^{o}$. For scan angles greater than approximately $\pm 60^{o}$ from boresight the antenna gain deteriorates to below a useful level. Allowing for losses in the feed and phase shifters the antenna would have a gain of about 30 dB at boresight falling to about 28 dB at $\pm 50^{o}$.

Although the principle of PA's is simple, their realisation is not. Again, to remain with the example of the X-band array, a single axis array with monopulse would require about 100 phase shifters i.e. 2 for each row or column (200 if electronic polarisation switching is used), and a 2-axis array would require anything up to 6000 phase shifters i.e. one for each element or two if polarisation switching is used. The feed would need to produce 1100 up to 6000 individual output ports which need to be connected to the radiator elements: the wiring of the array alone is a very expensive operation and the material costs can easily run into hundreds of thousands of dollars. Because of this, development of airborne arrays has concentrated on integrating components (such as the phase shifter with the radiating element) as well as reducing the component costs themselves. The problem of the cost and complexity of the feed can be avoided by using optical feeding (example: horn fed transmission or reflection arrays), although at the cost of high sidelobe levels. Another method with, for example, the one Axis X-band array is to use slotted guides as the fixed feeds and radiating elements. The problems in this case are low bandwidth and poor cross-polarisation (the slots must be in the narrow wall of the guide to avoid grating lobes when scanning).

A major improvement in performance can be obtained by using active array. Here, each radiating element is equipped with a transmit/receive module (Austin, J., 1980) (Fig.8). Beam forming is carried out on the transmit side in a reference line where loss is not important and the power level is low. The signal is then amplified and transmitted. On the receive side, the signal is mixed down in a quadrature demodulator and then converted into a digital signal (Barton, P., 1980). Beam forming is carried out using a beam forming processor. By duplicating the processor another, independent, receive beam can be formed (however the transmit beam must also be formed in such a way to illuminate both directions). The major advantage of the active antenna is that amplitude and phase errors on the microwave side can be compensated for in the processor which can lead to very low sidelobe levels. The reference feeds need only provide a phase reference and can, therefore, be much lossier than is the case with normal phased arrays. Once the T/R module has been developed as a MIC the cost of the antenna will fall. Active elements also permit the construction of Conformal Arrays where the radiating elements could, for example, cover the surface of the aircraft nose: this would permit $>180^{o}$ coverage in both elevation and azimuth.

At the present time, the major factor preventing the inception of phased array is their high cost. At AEG-TELEFUNKEN we are examining the 1-axis, constrained feed solution which gives a great saving in phase-shifters, and also a low cost, reflect array using horn-feeding.

Fig. 9 shows a photograph of the 1-axis, X-band array model. Here the azimuth feeding is carried out by a 1:48 series waveguide feed with coaxial outputs. The feed is split in the centre to provide azimuth-monopulse and connected to 48, 4-bit diode phase shifters capable of handling 2 kW. peak with a loss of about 1.5 dB. The phase shifters are connected to triplate feeds for the elevation beam forming, which, in turn, feed microstrip radiators. Note that the radiators have two orthogonal inputs which allows the radiated prolarisation to be electrically changed. Another possiblity is to radiate and receive two independent beams which are polarisation decoupled. In the model the elevation feed has been kept to four

radiators: the full antenna would have a circular aperture.

The second model, Fig. 10, operates in Ku-band and uses a very simple microstrip radiator and a 180° phase shifter as the antenna element. This would allow a very inexpensive two-axis array to be realised, but the available sidelobe rejection is limited because of the coarse phase quantisation. A 2-bit phase shifter would provide sidelobes of the order of 25 - 30 dB but it is very much more difficult to realise cheaply. Here, a finline phase shifter has been developed which can be inserted into a section of waveguide. The antenna aperture would be constructed with a triangular lattice of waveguide radiators.

To sum up, conventional phased arrays provide many advantages over the currently used flatplate antennas. More reliability and better electrical performance, because of the multibeam possibilities, can be achieved with active arrays.

5. THE ADAPTIVE MULTISENSOR SYSTEM

It is clear from the previous discussion that the radar cannot work in isolation but must form an integral part of the aircraft's total avionic system. All the sensors of this system must supply information to the aircraft's central computer for processing. The computer must then make decisions or decide on threat priorities and supply this information on the pilot in an optimal form so that he can formulate his course of action as speedily as possible. The complexity of such a system can be seen in Fig. 11, which shows the outputs required from the different sensors of the aircraft during the attack phase of the mission. It is clear that when the pilot is engaged in attacking the ground target he cannot afford to spend a great deal of time monitoring the various threat warning sensors such as a Tail Warning System (TWS) or the Radar Warning Receiver (RWR). Thus the aircraft is during this phase very vulnerable to attack from SAM's and aircraft on Combat Air Patrol (CAP) and this is the time where the greatest density of defensive capability can be expected.

A possible solution is for the sensors automatically to act without consulting the aircrew (Murphy. W.J., 1980). This, however, would be fiercely resisted by the flying team who like to think that they are in control of all aspects of the flight. The problem of how to involve the pilot in the Decision Making/Executive process can be approached by considering the incorporation of an adaptive task-sharing system (Fig. 12). Here information from the various sensors is fed into the central processor. From this information the processor must identify and classify the different threats and assign differing priorities. This threat priority could be assigned on a $R/\dot{R}$ basis (R is the range) although other algorithms could be employed. The processor then informs the pilot of the threat and allows him a threat dependent time in which to dispense countermeasures, perform evasive manoeuvres, fire defensive weapons or even break-off the attack as he sees fit.

If the pilot, because of his heavy workload, has not reacted within the allowed time then the processor must be able to perform the appropirate action autonomously.

The concept of adaptive task-sharing applied to an aircraft environment has been recently reported by Chu and Rouse (1979) and Walden and Rouse (1978). Rouse (1977) has shown that in order that the quality of the machine's decision approaches that of the human it would require the same length of time or longer. Thus we would, in effect, be no better off than without the processor.

A possible way out of this problem is to supply the machine decision-maker with pre-programmed decision trees as shown, for example, in Fig. 13. This example is the decision tree of Watson, Weiss and Donnell (1979) for a shoot/no shoot situation but similar trees could be contructed for other decisions such as whether to dispense countermeasures or not. The sensors supply the values of the probabilities $P_1, \ldots P_n$ and the utilities of the flight crew could be entered, perhaps as a cassette, before take-off. It can be shown that this system, where it acts automatically, would decide in exactly the same way as the crew would if it had the time do decide.

6. CONCLUSIONS

The strike mission, especially the attack phase, imposes special requirements on the aircrew. Firstly the weapons must be accurately delivered onto the target and, secondly, in the crews own interest and in the interest of the success of the mission threats to the aircraft must be overcome.

An advanced avionic system should be able to support the crew in the following ways: in addition to Terrain Following and Ground Mapping operations Air to Air search and Tracking modes are required. All these modes must be able to operate simultaneously as and when they are required. Key components for such a system are an electronically scanned antenna and a processor capable of processing the information available.

With the conventional phased array antennas at present under development where the power is centrally produced the different modes must be performed sequentially. The use of an active array, that is an antenna where each element is equipped with a Transmit/Receive module, allows a greater flexibility in performance. Such an antenna allows simultaneous, optimally shaped beams to be formed for every mode. These beams can be steered independently and the information from each beam processed seperately.

work on passive phased array antennas that could later lead to active arrays has been reported. Finally, ways in which the information from the nose radar could be integrated with that from other sensors has been discussed.

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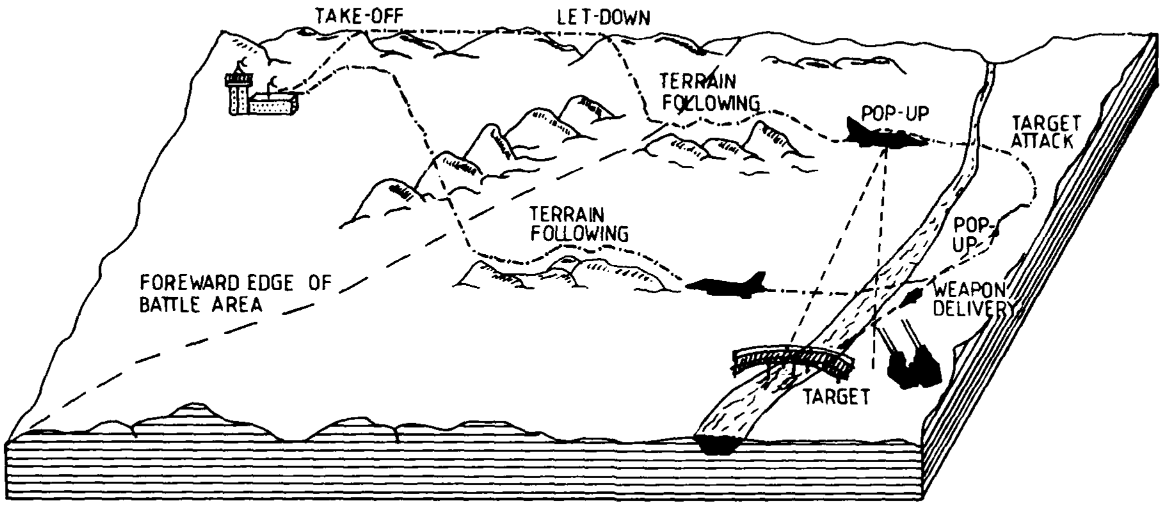

Fig.1 Typical interdiction mission

PHASE	MODES REQUIRED
CRUISE	REAL BEAM GROUND MAP (RBGM) DOPPLER BEAM SHARPENING (DBS)
LET-DOWN	TERRAIN CLEARANCE TERRAIN AVOIDANCE (TA)
INGRESS	TERRAIN FOLLOWING (TF) TA
TARGET AQUISITION	TF ,TA GROUND MOVING TARGET INDICATION (GMTI) HIGH RESOLUTION GROUND MAP
TARGET TRACKING	TF , TA GROUND MOVING TARGET TRACK (GMTT) GROUND FIXED TARGET TRACK (FTT)
WEAPON RELEASE	TF, TA, GMTT, FTT AIR / GROUND RANGING
EGRESS	TF, TA, RBGM, DBS,

Fig.2 Modes required during the various phases of the mission

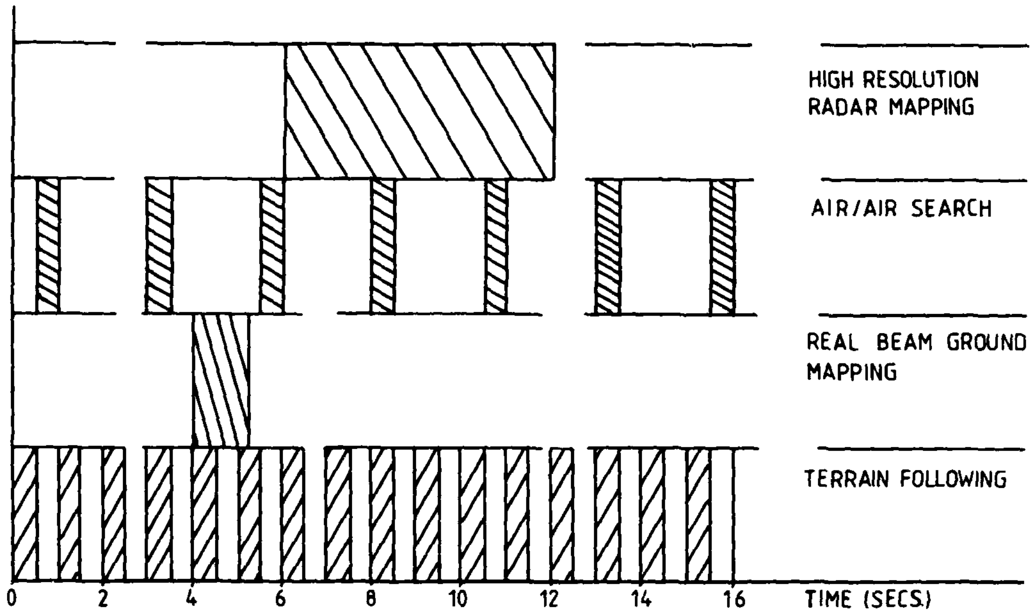

Fig.3 Possible required mode-mix during a mission

MODE/FUNCTION	CAPABILITY	COMMENTS
REAL BEAM GROUND MAP (RBGM)	RANGES SELECTABLE BETWEEN 10 AND 250KM 4:1 EXPANDED SCALE.	PENCIL/SPOILED BEAMS.CHOICE OF PRF DEPENDING ON RANGE.
DOPPLER BEAM SHARPENING (DBS)	15m RANGE RESOLUTION UP TO 40:1 RESOLUTION IMPROVEMENT. RANGE: 140 KM	MOTION COMPEN-SATION REQUI-RED
SPOTLIGHT	15×15 METER RES. RANGE: 140 KM 3×3 METER RES. RANGE: 50 KM	FOR NAVIGATION AND LARGE TAR-GET DETECTION
GROUND MOVING TARGET INDICATION AND TRACK	15 METER RANGE RES. RANGE: 50 KM	
TERRAIN FOLLOWING TERRAIN AVOIDANCE (TF, TA)	20KM PROFILE, 30METER MIN. CLEARANCE HEIGHT.	
AIR/AIR SEARCH/ SINGLE TARGET TRACK	NOMINAL RANGE VS 5m^2 TARGETS: 90 - 100 KM	
TRACK WHILE SCAN (TWS)	8 - 12 TARGETS MIN.	
VELOCITY SEARCH/ RANGE WHILE SEARCH	HIGH PRF MODES NECESSARY	
OTHER MODES/ PROPERTIES	IFF, MISSILE ILLUMINATION AND BEACON MODE COMPA-TIBILITY ARE DESIRABLE.	

Fig.4 Operational requirements during various phases of the mission

ANTENNA	TERRAIN FOLLOWING	GROUND MAPPING (PENCIL BEAM)	GROUND MAPPING (SPOILED BEAM)	AIR-AIR MODES
ANTENNA BEAMWIDTH AZI EL.	5° 5°	3° 3°	3° $COSEC^2$	3° 3°
ANTENNA GAIN	25dB	33dB	30dB	33dB
RMS SIDELOBE LEVELS W.R.T. MAIN BEAM	-35dB	-50dB	-35dB	-50dB
ANTENNA SCAN RATE	120°/SEC	100°/SEC	100°/SEC	100°/SEC
REQUIRED ANGULAR COVERAGE: AZI EL.	±12° +10°, -20°	±60° +5°, -30°	±60° +5°, -30°	±70° ±60°
TRANSMITTER POWER (PEAK)	60KW	15KW	15KW	15KW,1.5KW
PULSE LENGTH				1,5μS
PRF	3KHZ	3KHZ	3KHZ	3KHZ,30KHZ, 300KHZ

Fig.5 Radar parameters for various modes of operation

MODE (FUNCTION)	REQUIRED DWELL TIME (SEC)	REQUIRED FRAME TIME (SEC)	REQUIRED MISSION UPDATE RATE (SEC)
REAL BEAM GROUND MAP (RBGM)	0,03	1,2	OCCASIONAL
DOPPLER BEAM SHARPENING (DBS)	DEPENDS ON SCAN ANGLE (0,5MAX)	2 - 3	OCCASSIONAL
SPOTLIGHT	4 - 6	4 - 6	OCCASSIONAL
GROUND MOVING TARGET INDICATION AND TRACK (GMTI/GMTT)	0,02	1	1 (DURING ATTACK PHASE ONLY)
TERRAIN FOLLOW	0,025	0,5	0,5
A-A SEARCH SHORT RANGE (20KM)	0,01	0,5	3
LONG RANGE (100KM)	0,05	2,5	100
A-A TRACK	TARGET DEPENDENT		

Fig.6 Required dwell times, frame times and information update rates for the various radar modes

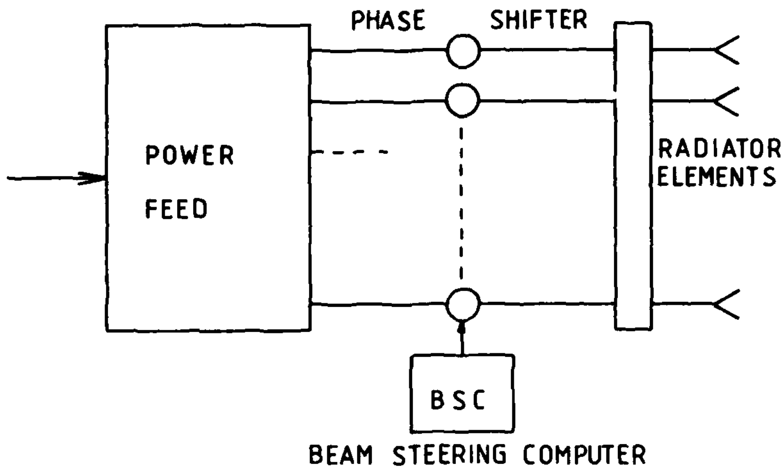

Fig.7 A simplified phased array

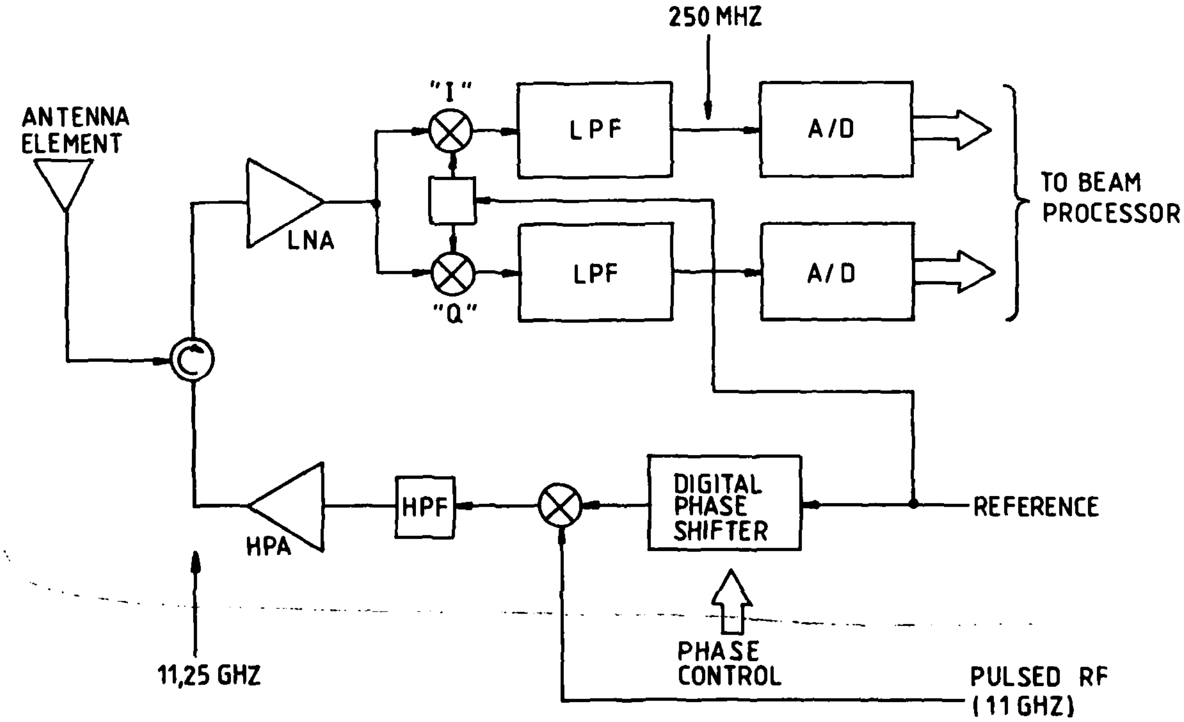

Fig.8 An active array system

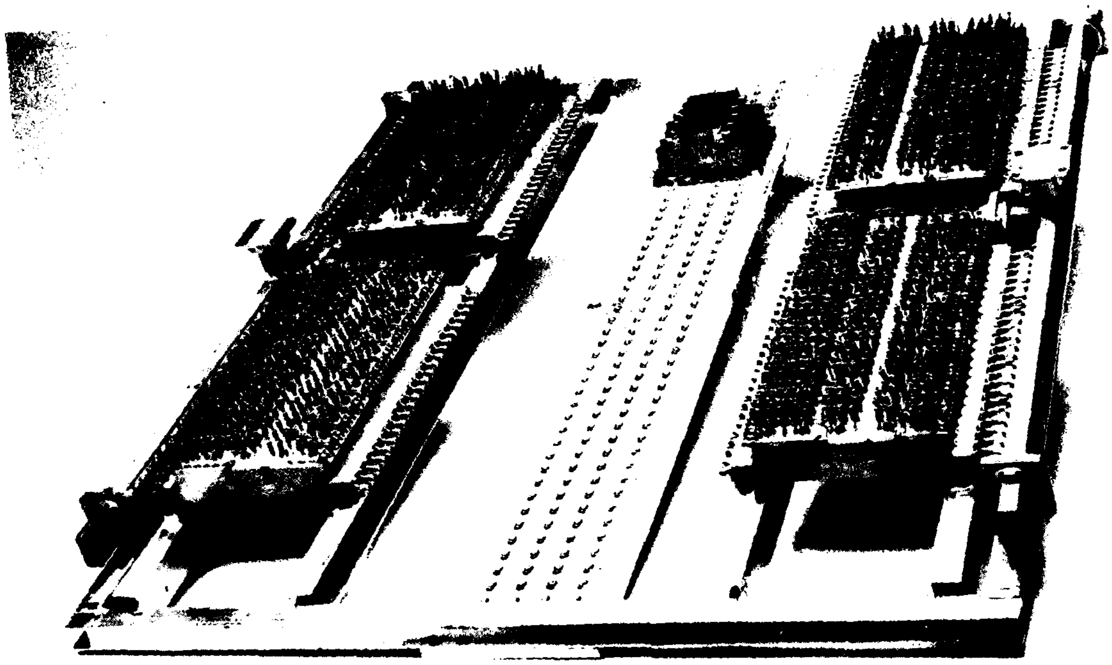

Fig.9 Model of a one-axis, X-band array

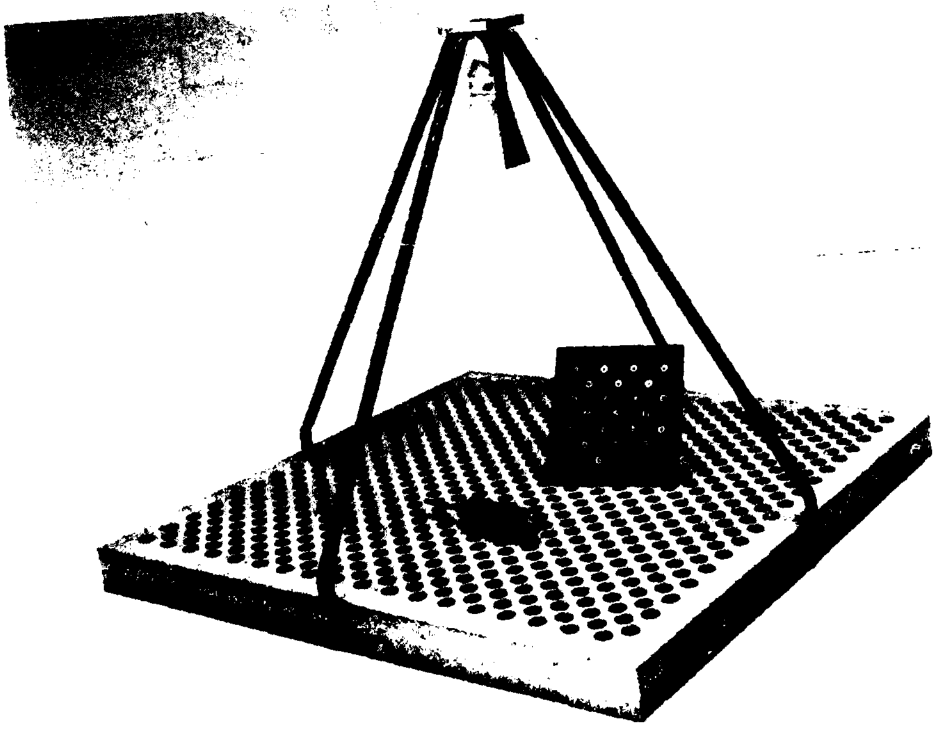

Fig.10 Model of the Ku-band array

SOURCE	PARAMETER
ELECTRO OPTICAL TRACKER	TARGET ANGLE RATES AND POSITION TARGET TRACKING ERRORS TARGET RANGE STATUS OF TRACKER
NOSE RADAR	ANTENNA ANGLE RATES AND POSITION TARGET RANGE A/C CLEARANCE HEIGHT NAVIGATION UPDATE RADAR STATUS
INERTIAL NAVIGATION SYSTEM	INERTIAL VELOCITIES AND A/C POSITION A/C ATTITUDE
RADAR WARNING RECEIVER	THREATS AND THREAT STATUS
TAIL WARNING SYSTEM	WARNING OF THREATS FROM THE REAR HEMISPHERE
A/C AIR DATA SYSTEM	AIRSPEED ANGLE OF ATTACK RELATIVE AIR DENSITY BAROMETRIC PRESSURE ALTITUDE
FLIGHT CONTROL	A/C BODY RATES AND ACCELERATION

Fig.11 Outputs from the sensors during the attack phase

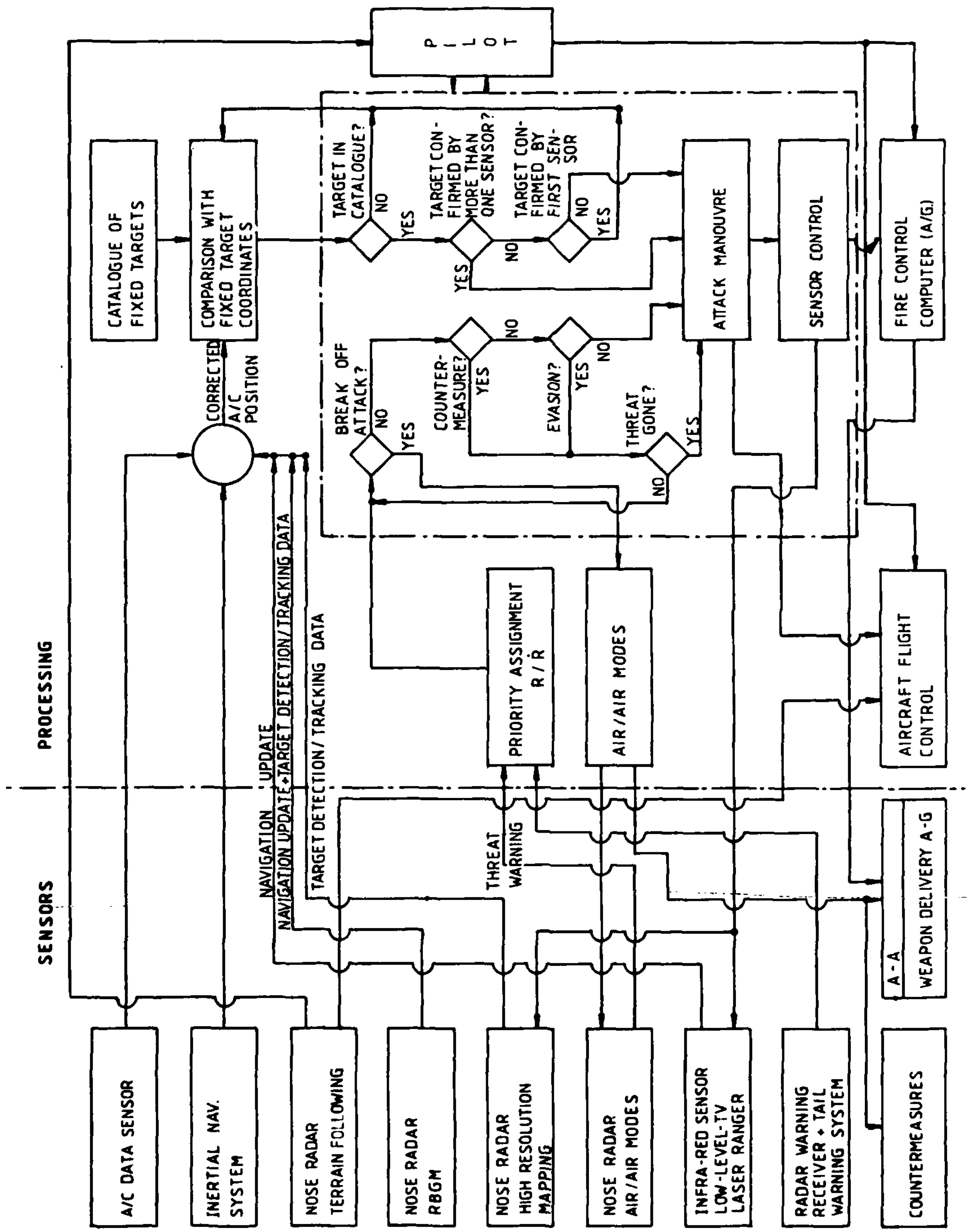

Fig.12 A multi-sensor system for the air/ground mission

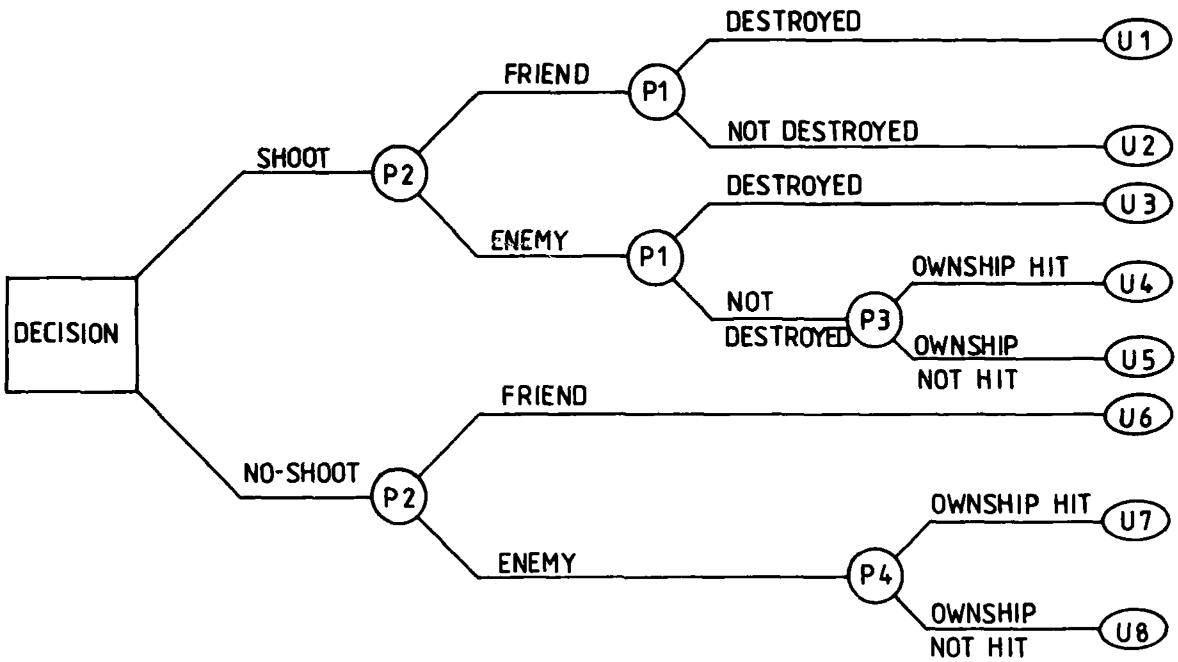

Fig.13 Decision tree "shoot/no shoot"

P 1 = PROBABILITY THAT THE TARGET WAS DESTROYED

P 2 = " " " " IS A FRIEND

P 3 = " " " " WILL HIT OWNSHIP AFTER A MISS FROM US

P 4 = " " " " WILL HIT US IF WE DO NOT SHOOT

UTILITIES

SHOOT

P2 [U1P1—U2 (1-P1)] + (1-P2) [U3 P1 + (1-P1)[U4 P3 + U5 (1-P3)]]

NO - SHOOT

P2 U6 + (1-P2) [U7 P4 + U8 (1-P4)]

Fig.14 Clarification of the decision tree

ATTACK AND EN ROUTE AVIONICS FOR IN-WEATHER OPERATIONS

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SUMMARY

An increasingly sophisticated and lethal ground threat environment must be countered in large part by technological advances in the avionics of naval attack aircraft. Critical deficiencies now exist in the areas of standoff targeting and weapons delivery, defense suppression, equipment reliability, and crew loading. To reduce pilot work load, automated procedures and decision aids must be developed. Technology must be made available for precise navigation, integration of weapon delivery and flight control systems, automatic target recognition, detection avoidance, automatic flight path routing, and secure communications. The complexity of future avionics systems will require increased emphasis on reliability to assure fully operational aircraft.

This paper is primarily concerned with the ingress and egress and attack phases of the naval air mission, but defense suppression is also considered as an integral mission function in assuring force survivability.

1. INTRODUCTION

This paper addresses future trends in both en route avionics and attack avionics for in-weather operations by naval aircraft. These trends will be discussed in the context of the threat evolution since World War II and the impact of the evolving threats on both the ingress and egress and the attack phases of the mission. Particular emphasis will be placed on the implications of these threats for force survivability.

2. NAVAL AIR ATTACK MISSIONS

Naval air attack missions have been primarily concerned with support of the war at sea, but the Navy has a growing responsibility in support of tactical warfare ashore, including close air support (CAS) for Marine Corps amphibious landing operations, interdiction, and deep strike. Defense suppression has a growing importance as a result of the development of sophisticated enemy ground defenses and their impact on force survivability. However, it should be recognized that defense suppression is an "overhead" function; while it is vital to insure the survivability of our forces, it does not contribute directly to the primary attack missions. In fact, most defense suppression operations reduce the aircraft and weapons available for those primary attack missions.

2.1 Targets

Figure 2.1 illustrates representative targets that will be encountered in a surface support mode. En route to the amphibious landing site, the force will encounter both single ships and groups of ships in the open ocean. As the force approaches the landing site, enemy patrol craft and port gun emplacements will be encountered. The next order of targets will be bridges, armored vehicles, and command posts close to the forward edge of battle. Finally, in areas far behind the battle zone, the targets will include resupply areas and airfields. Surface-to-air missile (SAM) sites will be encountered throughout the overland route.

2.2. Close Air Support

In the CAS mission, carrier-based tactical aircraft are required to support ground forces prior to the establishment of Marine Corps aircraft landing sites. The CAS mission requires precision ordnance delivery during the day, at night, and in adverse weather. The precision is of great importance because of the need to attack targets in close proximity to our own forces. The capability for ground-controlled target location would enhance accuracy of delivery. The aircraft that will be used for the CAS mission will be the A-6E, A-7, and F/A-18.

2.3. Interdiction

The interdiction mission involves the disruption and destruction of hostile forces, supplies, and communications behind the battle zone. These targets are beyond the view of the forward air controller; and the attack must be accomplished in day, night, and adverse weather conditions. The targets are protected by air defense systems, including mobile antiaircraft artillery and SAM systems as well as fixed SAM sites. Identification, friend or foe (IFF) systems will be critical factors in the successful accomplishment of this mission. The aircraft used in the interdiction mission also will be the A-6E, A-7, and F/A-18.

2.4 Deep Strike

The primary purpose of the deep strike mission is to immobilize air support and logistics facilities by destroying such targets as airfields, marshaling centers, industrial sites, and bridges. These targets will be heavily defended by both ground systems and air interceptors. Deep strike attacks will be conducted in day, night, and adverse weather conditions by the A-6E and the F/A-18 aircraft.

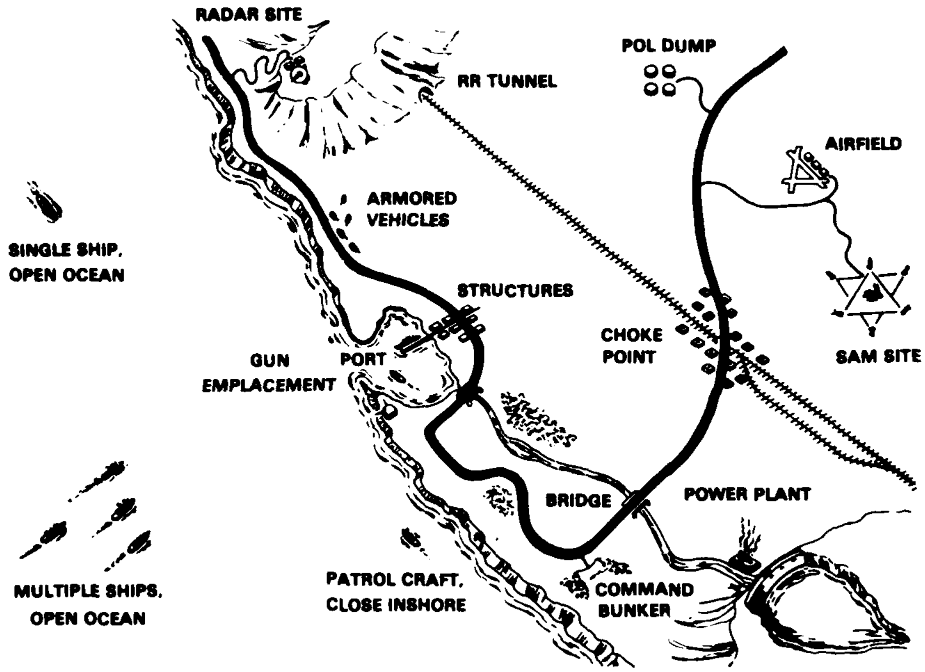

FIGURE 2.1. Representative Tact‑‑al Surface Targets.

2.5 Defense Suppression

Defense suppression will be an integral and vital part of all these missions, as the following discussion will illustrate.

3. THREAT AND TACTICS EVOLUTION

3.1 Attack Aircraft

Aircraft that have been used in performing the Navy attack missions from World War II up to the present are

- BT-1
- SBD Dauntless
- SB2C Helldiver
- A-1 (1944)
- A-4 (1952)
- A-6 (1958)
- A-7 (1964)
- A-18

The A-6 aircraft, which was introduced in 1958, is still being used as the backbone of the Navy's *all-weather attack operations.* The A-7 aircraft does not have the all-weather capability of the A-6, partly because it does not have as good a radar and partly because it is a single-seat aircraft. The A-18, which is entering the Fleet today, is also a single-seat aircraft.

3.2. Early Threats and Tactics

Figure 3.1 illustrates the attack tactics used during World War II and the Korean conflict. The ground threat consisted of antiaircraft artillery and small arms fire having a limited ceiling. By maintaining a high altitude during ingress and egress, exposure to ground defense could be minimized. Targets were acquired visually and dive-bombing weapon delivery tactics were employed.

During the Vietnam War, the ground threat became more sophisticated as a result of the development of SAM systems. As illustrated in Figure 3.2, we still maintained high-altitude ingress and egress and dive-bombing weapon delivery tactics, but our aircraft could no longer always fly above the ceiling of ground defenses. Nonetheless, our pilots learned how to outmaneuver the SAMs and, with rapid development of electronic support measure and electronic countermeasure (ESM and ECM) capabilities, were able to keep attrition to a manageable level.

3.3 Present Threats and Tactics

The present ground threat that would be encountered by Navy attack forces is entirely different than that of past conflicts. As illustrated in Figure 3.3, the operating ceiling of ground defenses exceeds the operating ceiling of our aircraft. The defenses have sophisticated electronic counter-countermeasure (ECCM) capability; and they are varied, mobile, and extremely lethal. To reduce our exposure time to these defenses, we have developed high-speed, low-altitude ingress and egress tactics. We are using a combination of visual, electro-optic (E-O), and some radar target acquisition techniques coupled with loft and pop-up weapon delivery tactics.

Current threat systems are capable of causing unacceptable attrition rates with conventional weapons and tactics. Moreover, these threat systems are possessed not only by the superpowers, but by virtually *all* potential adversaries. The weapons holdings of the armed forces of some Third World countries is formidable and, in some cases, considerably out of proportion with respect to real need. Libya, for example, has more tanks per capita than any country in the world; it has both NATO and Soviet aircraft in its inventory; and it has modern ground-based air defense systems.

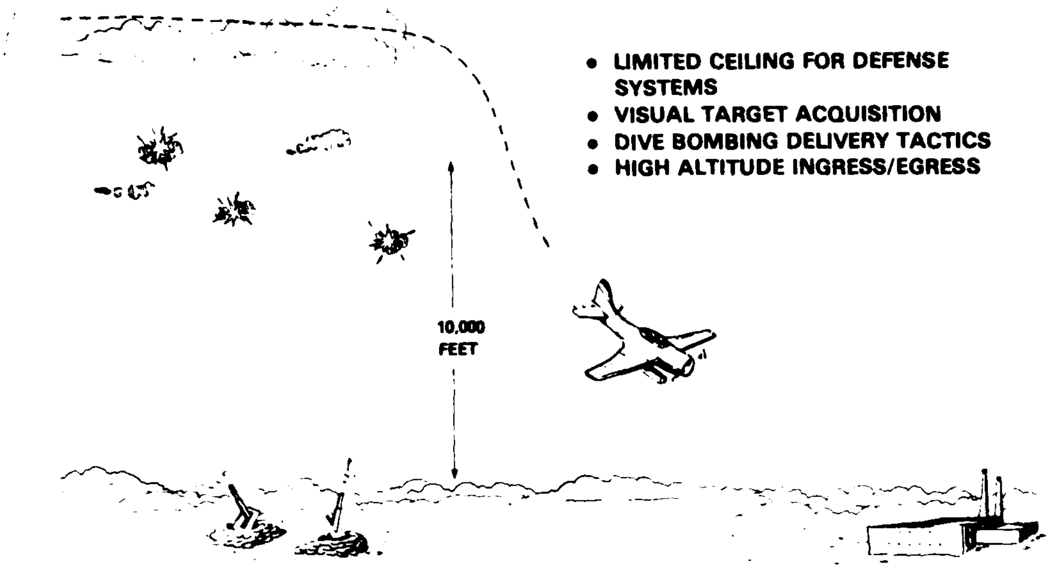

FIGURE 3.1. Ground Threat World War II and Korea.

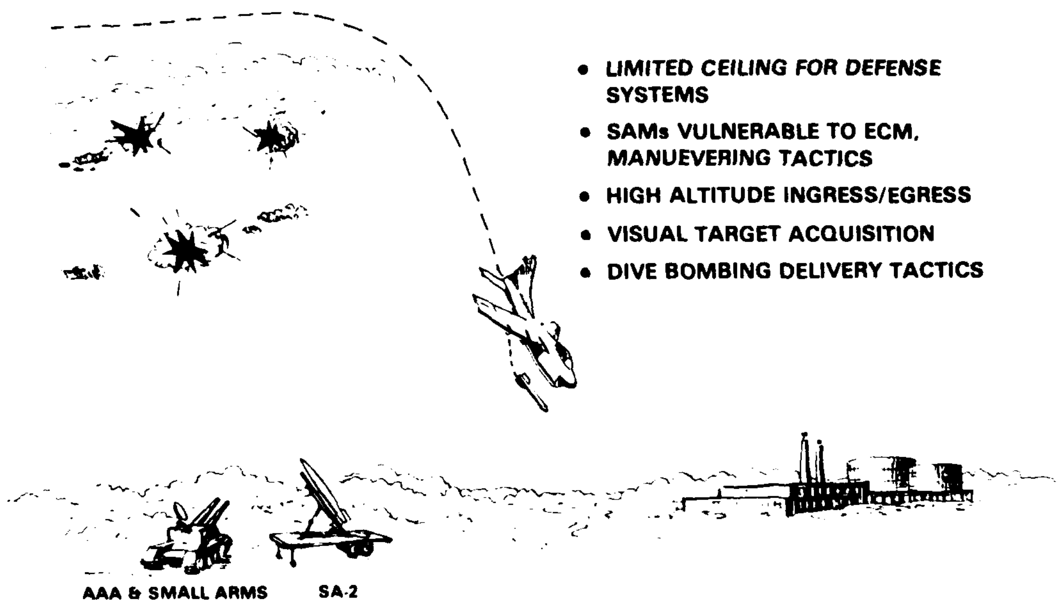

FIGURE 3.2. Ground Threat- Vietnam.

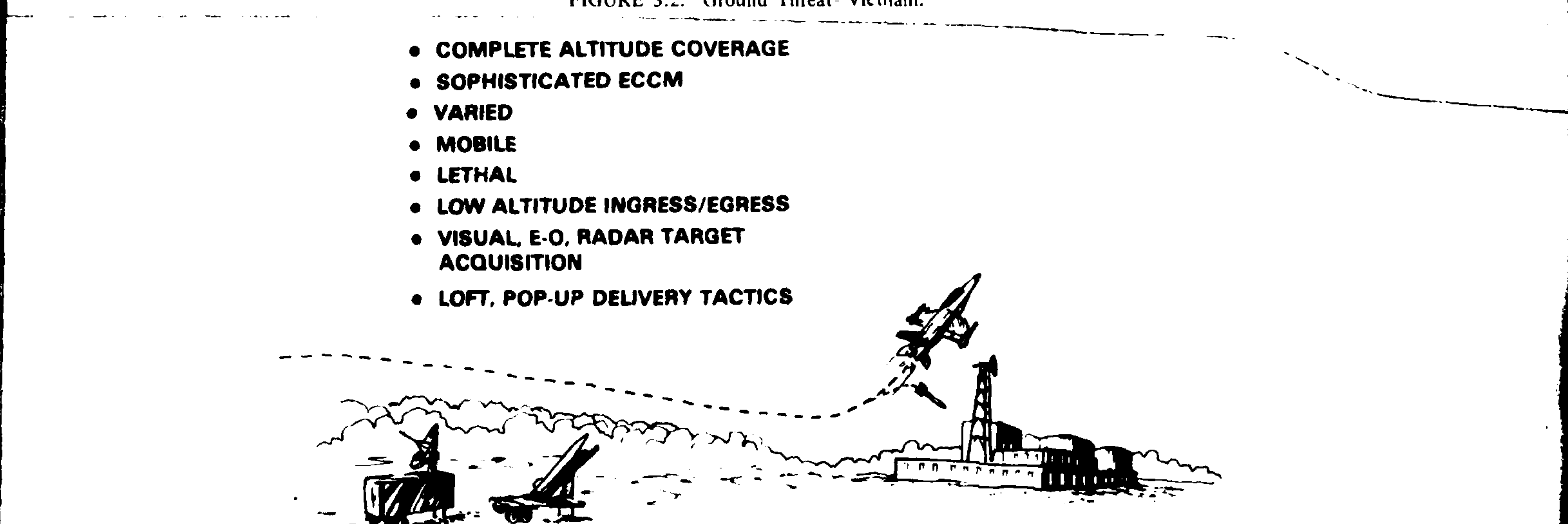

FIGURE 3.3. Ground Threat Present.

4. ATTRITION

The potential impact of these air defense systems on the sortie attrition rate is a function of both the single-shot kill probability (SSP_k) and the number of SAM encounters per sortie. Even if the SSP_k is assumed to be low, the number of SAM encounters that could be expected in a dense air defense will cause the attrition rate to increase to unacceptable levels (see Figure 4.1). If an SSP_k of .02 with one SAM encounter involving two missile firings is assumed, then the sortie attrition rate is 4%. If three SAM sites are encountered, then the sortie attrition rate climbs to 12%.

Force survival is extremely sensitive to simple, constant attrition, as illustrated in Figure 4.2. For a simple attrition rate of 4%, after 20 sorties less than half the force would be surviving. For an attrition rate of 12%, virtually no aircraft would remain after 20 sorties. Since modern carrier-based aircraft often fly three sorties a day, it is clear that these attrition rates cannot be sustained. Since aircraft carriers are limited in the numbers of aircraft and weapons that can be carried, attrition is a particularly severe problem for the Navy. While some reduction in attrition can be accomplished through the reduction of SAM SSP_k by ECM, the most important parameter is the number of encounters. This can and must be reduced by destruction of the SAM sites, so that the attrition rates will not remain constant, and by flight path routing to avoid encounters.

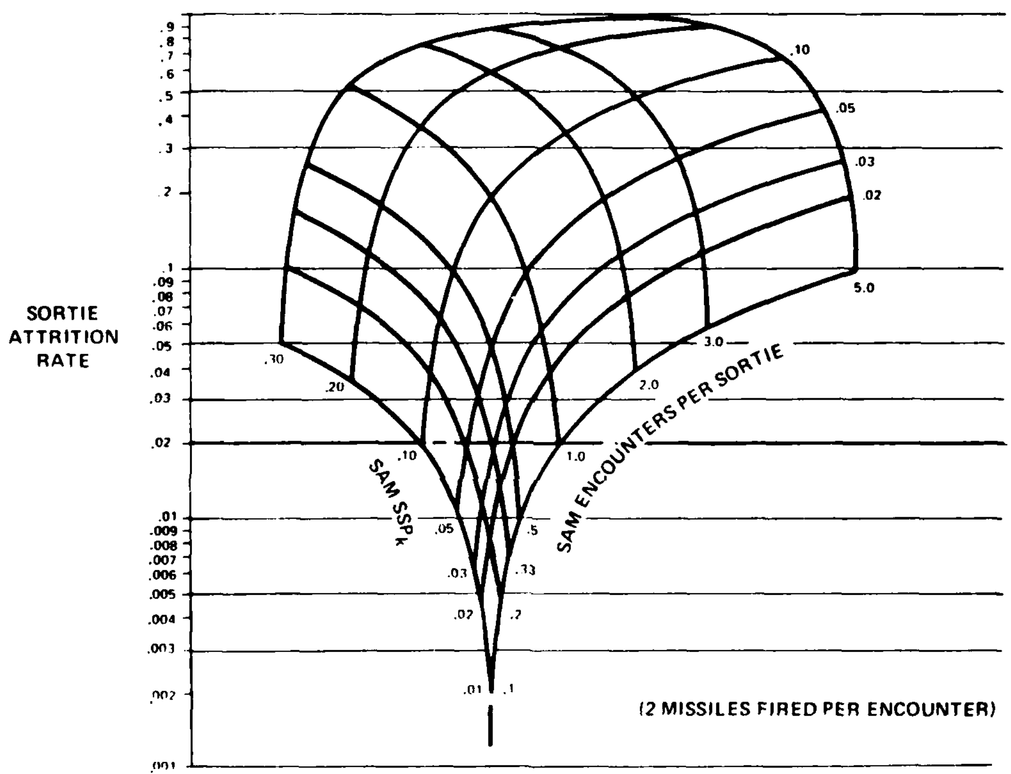

FIGURE 4.1. Effect of SAM P_k and Encounter Frequency on Attrition.

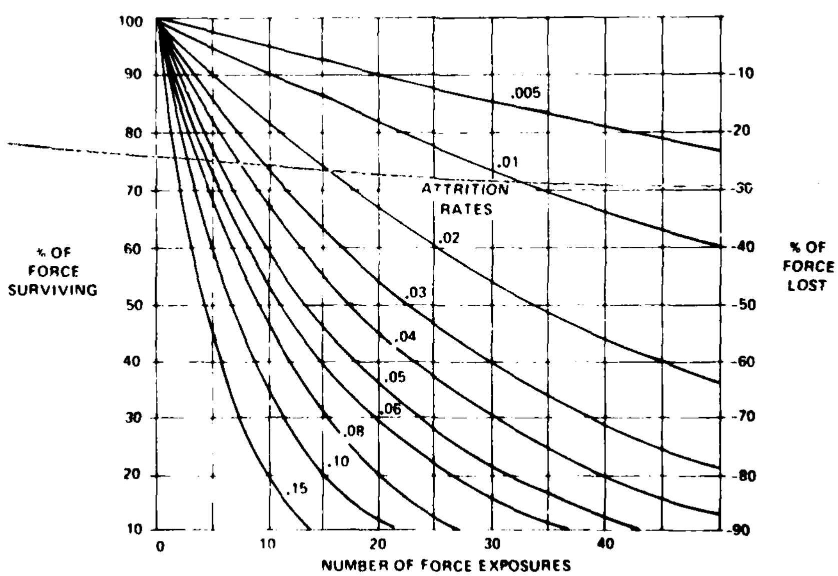

FIGURE 4.2. Sensitivity of Force Survival to Simple, Constant Attrition.

5. ATTACK PHASES

Targets that will be encountered in land attack missions range from soft area targets such as petroleum (POL) farms to extremely hard point targets such as hardened command, control, and communication (C^3) sites. Since enemy SAM forces are extremely well coordinated, the ability to knock out the enemy command and control capability is extremely important.

The weapons available to attack these targets have changed little since World War II. In 1945, the USS *Midway* strike weapons loadout was general purpose bombs, rockets, and gun ammunition. In 1980, the USS *Midway* carried the same primary weapons plus the Rockeye, Walleye, and Shrike/Standard Arm missiles.

Usually, a discussion of an air attack mission is concerned only with the terminal phase of the attack: target acquisition, weapon delivery, guidance, and possibly damage assessment.

However, the mission planning and ingress and egress phases of the attack are equally important. The highest attrition is likely to occur in the ingress and egress phases, and so careful mission planning for flight path routing and target and weapon selection is increasingly important to assure that the attack is successfully executed and the aircraft will survive to attack again.

6. INGRESS AND EGRESS

6.1 Mission Scenario

To discuss the ingress and egress phases of the attack problem, it is necessary to make some basic assumptions to define the problem. In a representative scenario, the first assumption is that operations are being conducted at night and in adverse weather. Air and sea superiority in the battle area has been established. The targets to be attacked are heavily defended with mobile defenses.

Figure 6.1 depicts the scenario just described. An aircraft carrier is operating a few hundred miles off the coastline and, as a result of the established air superiority, it is possible to keep tankers aloft as well as early-warning aircraft. Navigation satellites are also available for the updating of navigation. As the figure depicts, the attacking aircraft will take off from the carrier. They will rendezvous and ingress toward the target area. As the aircraft approach the coastline, they will drop down to a low level to use terrain masking to avoid detection. Operations in the target area and within 20 to 30 miles of the target, i.e., the attack phase, will be discussed later. The egress part of the problem is very similar to the ingress phase, with the only difference being that the enemy has surely been alerted; therefore, the egressing attacking force will certainly be under attack themselves. Successful egress may include rendezvous with the tanker. Finally, there will be loiter time in the vicinity of the carrier prior to aircraft recovery.

There are three primary problems en route. These are survivability, communication, and navigation. The problems and possible technological solutions to each of these will be discussed.

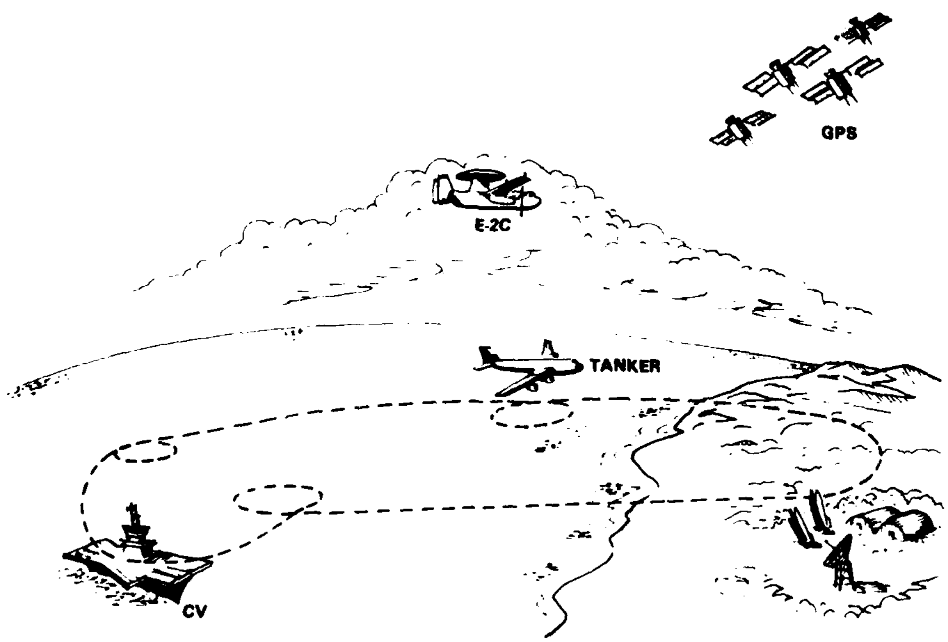

FIGURE 6.1. Mission Scenario, Night Attack in Adverse Weather.

6.2 Survivability

Table 6.1 lists some of the problems or functions currently existing in survivability, how these problems are currently dealt with, and possible future improvements.

TABLE 6.1. Present and Future Technology for Survivability Functions.

PROBLEM/FUNCTION	NOW	FUTURE
CREW LOADING	TWO MAN CREW	AUTOMATION
EQUIPT. AVAILABILITY	2-6 MFHBF	>20 MFHBF
AVOID DETECTION	EMCON <400 FT 360 KTS	LPI EMISSIONS <200 FT 600 KTS
THREAT AVOID.	ALR-45	ALR-67
COLLISION AVOID.	2-3 A/C @ 2-3 MIN.	AUTO POS. CONTROL

6.2.1 **Crew Loading.** Crew loading is a major problem. Discussions with the pilots and bombardier navigators at the Naval Weapons Center indicated that crew loading is the major factor when the aircrew is flying at low level in bad weather or at night. A two-man crew is fully occupied just flying the aircraft. Very little time is available to accomplish any kind of attack function, such as finding the target. In the future, automation of as many cockpit functions as possible may help to alleviate the crew loading problem.

6.2.2. **Reliability**. Reliability is an area leaving much to be desired at this time. Today, experience shows 2 to 6 mean flight hours between failures, but there is hope of achieving or exceeding 20 hours in the future. The point here is that, no matter how sophisticated the equipment aboard, if it's not working or if the pilot cannot rely on it, he will not, or cannot, use that equipment and therefore it might as well not be in the aircraft anyway.

6.2.3. **Detection Avoidance.** To avoid detection, emission control (EMCON) is exercised, and aircraft fly as low and fast as is dared. In general, depending on the terrain, this is less than 400 feet altitude. Obviously, the faster the attacking aircraft can get in and back out again, the less chance of detection and thus the higher the survivability. In the stated environment, the aircraft speed is usually 350 to 400 knots. In the future, technology should allow flight at less than 200 feet and at speeds of 450 to 600 knots.

6.2.4. **Threat Avoidance.** The ALR-45 radar homing and warning receiver is now used for threat avoidance. In the future, the ALR-67 will afford significant improvements.

6.2.5. **Collision Avoidance.** Collision avoidance is a serious problem. In bad weather or limited visibility only two or three aircraft are sent in an attacking force. They are spaced 2 to 3 minutes apart so they don't have to worry too much about running into each other and can concentrate on not running into the terrain. With this spacing, the first one in may have the element of surprise, but the other two must contend with an enemy that is expecting them and is fully prepared. What is needed in the future is an automatic positioning system. In other words, by using something like the Joint Tactical Information Distribution System (JTIDS) data link, more accurate relative positions can be achieved.

6.2.6. **Future Technologies.** Table 6.2 lists the major technologies that can enhance survivability in the future.

TABLE 6.2. Technologies for Survivability.

- INTEGRATED, AUTOMATED CONTR. & DISPLAY
- LPI SENSOR SYSTEMS
- PRECISE NAVIGATION
- ESM & ECM
- VAC & VOICE SYNTHESIZERS
- ATF/ATA
- VHSIC
- DEFENSE SUPPRESSION

6.2.6.1. **Integrated, Automated Control and Display.** Integrated, automated control and display is an approach to minimizing crew loading so that more time can be devoted to the attack functions. Figure 6.2 shows the layout of the F-18 cockpit. This design is a major step toward achievement of an automated control and display system. Visible in the picture are three cathode ray tube (CRT) displays, the master monitor display (left), the multifunction display (right), and the electronic horizontal situation indicator. These displays are, in general, interchangeable, and can display anything from aircraft-store status to the electronic map, radar, and forward-looking infrared (FLIR) displays. In addition, the head-up display and the up-front control panel put all the functions required for the attack mission directly in front of the pilot.

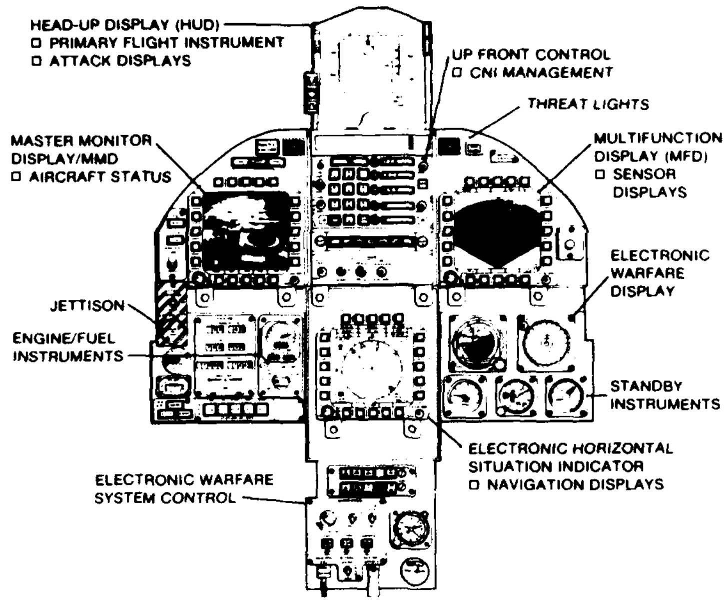

FIGURE 6.2. F/A-18 Cockpit Layout.

6.2.6.2. **Low Probability of Intercept.** An emerging technology in the low probability of intercept (LPI) area is the CO_2 laser radar. The CO_2 laser radar offers extremely high resolution. Its range is limited, but it offers a very narrow beam width and power management so that it can be operated without much fear of detection.

6.2.6.3. **Precise Navigation.** Precise navigation is required to facilitate flying the correct route. It doesn't do any good to plan a route for minimum detectability during ingress or egress unless it is possible to fly that route with reasonable precision.

6.2.6.4. **Electronic Support and Electronic Countermeasures.** In the ESM, ECM areas, jammers, radar warning receivers, deceivers, and chaff will all be improved. These areas will experience increasing support in the future.

6.2.6.5. **Voice-Activated Controls, Voice Synthesizers.** A very interesting technology area is that of voice-activated controls (VAC) and voice synthesizers. The military, as usual, lag in application of these advanced technologies. Whereas commercial industry is using both VAC and voice synthesizers in their stocking, routing, and inventory control, no military use has been attempted. Use of VAC could eliminate some of the crew work load, i.e., the pilot would not have to remove his hands to switch modes or change frequencies. He could simply speak, and the proper activation would take place. Voice synthesizers could be used effectively for advisories to the pilot. It has been shown that people react to different tones of voice. For instance, one of the methods being discussed is that of routine advisories being given in a male voice, with an emergency advisory given in a female tone of voice. The pilot would immediately recognize that an emergency situation existed and would be alerted for a rapid reaction.

6.2.6.6. **Automatic Terrain Following, Automatic Terrain Avoidance.** To continue the list of Table 6.2: automatic terrain following and automatic terrain avoidance (ATF, ATA) are very important in the night and/or adverse weather attack role. Figure 6.3 depicts the F-18 terrain avoidance implementation. It provides the pilot knowledge of two planes, one on the aircraft velocity vector, and one a specified altitude below the velocity vector. This information is sufficient to fly the aircraft; however, there is nothing automatic about it.

FIGURE 6.3. F/A-18 Terrain Avoidance Implementation.

Figure 6.4 shows the A-7 aircraft with a FLIR pod attached. Vought has mechanized the A-7 forward-looking radar and radar altimeter into an automatic terrain-following system coupled into the autopilot, operable at night using FLIR video for the pilot display. Flights were made over fairly rugged terrain in West Texas at 200 and 500 feet preset altitude levels. The initial results look promising.

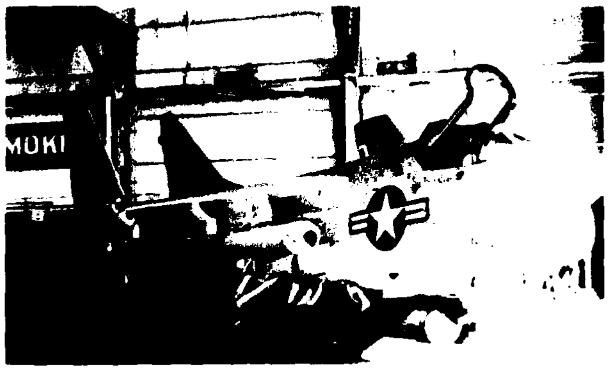

FIGURE 6.4 A-7 Aircraft With FLIR Pod.

6.2.6.7. **Defense Suppression.** Finally, defense suppression must be considered. Figure 6.5 shows a typical scenario for an attack mission. You can see the setup of the enemy defenses: the early warnings, the SA-4, SA-6, SA-2, SA-8, and ZSU-234 missiles. The Iron Hand aircraft stand off somewhat and provide defense suppression for protection of the strike aircraft. This is reasonably effective, but a real need is for a small, low-cost antiradiation missile that could be carried on the attacking aircraft so that they could have an immediate response capability when they detect a threat. With this limited-capability weapon, they would not have to totally rely on the Iron Hand aircraft for their only defense against SAMs.

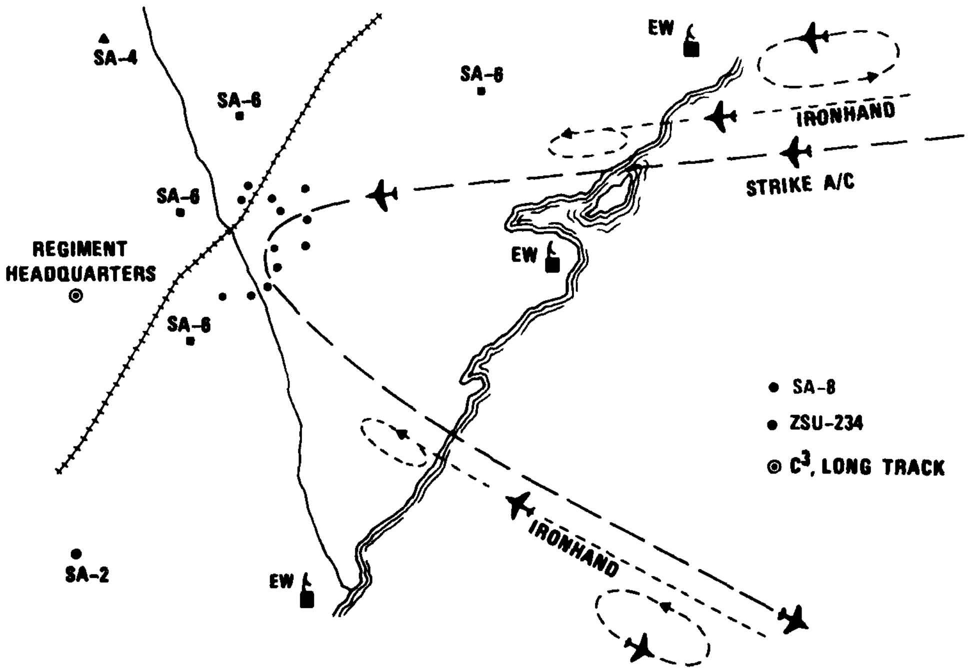

FIGURE 6.5. Attack Scenario With Iron Hand Aircraft in Defense Suppression Role.

6.3. Communication

We must next consider communications problems. The initialization function is one that takes time. Radio and IFF frequencies and codes now have to be set manually. This operation could be automatic in the future. It could even be handled over a data link prior to the aircraft taking off from the carrier. Voice now is analog or encrypted UHF and VHF. Problems that are experienced in the encrypted version are voice delays and poor fidelity. Anyone who has heard the dialog on a typical mission, or when approaching an airport, knows that transmissions are often garbled (you often wonder why we don't have more accidents because of the poor communications). With future very-high-speed integrated circuits (VHSIC), it should be possible to operate in real time to eliminate both the problems of delayed voice due to encryption and the garbled transmissions while still maintaining security. Digital data links now have low capacity; in the future, with JTIDS, we hope to have high-speed, accurate, two-way, secure wide-band capability. Some of the technologies available or under development that could enhance communications are tabulated in Table 6.3.

TABLE 6.3. Technologies for Communication.

- **VOICE RECOGNITION & SYNTHESIS**
- **DIGITAL SYSTEMS**
- **TDMA/DTDMA**
- **LASER COMMUNICATIONS**
- **VHSIC**

6.3.1. **Voice Recognition and Synthesizer.** What has been previously described regarding voice recognition and synthesis can be effectively utilized in controlling communications and improving the fidelity. For example, technology will permit a so-called standard voice. A person could speak, as we all know, with a different sounding midwest or northeast accent, and so forth, and the voice we use on a radio is often difficult to understand. To overcome this difficulty, a rapid voice recognizer and synthesizer could provide communications wherein everyone sounds the same, with the same crisp tone. The negative aspect of this idea is that we all interpret the inflections or changes in a person's voice to gain additional information or emphasis. A detailed human factors study would be required to determine the real worth of this approach.

6.3.2. **Digital Systems.** Digital systems are now a way of life to avionics designers. In communications, they will allow very rapid coding and decoding of information for encryption. They will also permit improvement of the fidelity of our systems. The volume and weight will continue to shrink.

6.3.3. **Time Division Multiple Access.** Time division multiple access (TDMA) and distributed TDMA systems will provide digital data links of extreme accuracy and capability. Systems such as JTIDS will service a very large spectrum of data link users as well as provide precise relative navigation.

6.3.4. **Laser Communications.** Laser communications will be used to provide very secure, very low probability of intercept, and jamming-resistant communications.

6.3.5. **Very-High-Spread Integrated Circuits.** VHSIC will provide high speed, reliability, small size, and low cost.

6.4. Navigation

Major problems and functions in the navigation area are shown in Table 6.4.

TABLE 6.4. Present and Future Technology for Navigation Functions.

PROBLEM/FUNCTION	NOW	FUTURE
DETERMINE ROUTE	MANUAL	AUTOMATED
DATA INSERTION	MANUAL	DATA LINK
NAV INITIALIZATION	HARD WIRE/DATA LINK	AUTONOMOUS/SATELLITE
ACCURACY	1-2 N.M./HR.	0.5 NM GEODETIC 100 FT. RELATIVE
TERRAIN RECOGNITION	RADAR/FLIR	HIGH RESOLUTION INTEG. SYS.

6.4.1. **Determination of Route.** For determining the route to be flown on an attack mission, the present procedure with crews on the A-6 aircraft requires that the bombardier/navigator spend about 1 1/2 hours with all of the geographic, target, and threat data he can find and that he manually plot his course. That information could be input into computers and an optimal route planned by the computer in a very, very short time. Experienced pilots and bombardier/navigators say they would rather do the planning themselves because that gives them a complete familiarity with the maps, the route they are going to fly, and the threats. This planning is an invaluable part of their preparations for the mission. This is certainly a valid point, but the primary concern is actually that they don't feel they could trust the computer to do as good a job as they could. It is felt that this computer technique should be developed and that bombardier/navigators should also be trained to manually plan their routes. After several interactions with the computer developing the same route, or even possibly a better route, confidence will be gained and the computer technique accepted with a significant savings in time.

6.4.2. **Data Insertion.** Data such as way points is now inserted manually. In the future, data links can and should be used to save time and minimize errors.

6.4.3. **Initialization.** In order to align an inertial navigation system, either a cable to connect the aircraft to the carrier navigation system or the ASW-25 data link is used. The problem is that if the link is hard-wired, the aircraft can't be moved. If it is data-linked, it violates EMCON. In the future, we should be able to do an autonomous initialization-alignment of the platform using satellites or JTIDS data link. The data link is not really autonomous but it is, or can be, independent of the carrier task force to minimize EMCON exposure.

6.4.4. **Accuracy.** Most of our systems are now in the accuracy range of 1 to 2 nmi/hr. In the future, it will be possible to get 1/2 nmi/hr in true inertial and better accuracy using JTIDS relative position capability.

6.4.5. **Terrain Recognition.** For terrain recognition at night or in adverse weather, we now use radars and FLIRs. Depending on the system, and the weather, they can be classified as fair to bad. In the future, we hope to field some very high-resolution synthetic aperture radars and high-resolution FLIRs. They should vastly improve our ability to pick out terrain features and the way points so that the selected route can be flown.

6.4.6. Developing Technologies

6.4.6.1. **Inertial Sensors.** Several technologies are available for enhancing navigation. The first one is inertial sensors. Figure 6.6 shown here is one of the most important developments in the last decade; a ring laser gyro (RLG). This gyro is manufactured by Honeywell, which has various contracts for this sensor. Their biggest contract is with Boeing for delivery of a commercial-grade navigation system for the Boeing 757/767 aircraft. Honeywell also has a contract with McDonnell Douglas to build an inertial navigation system using ring laser gyros (RLGN) for the AV-8B aircraft. This system is shown in Figure 6.7. Electrically and physically, it will be a direct replacement for the ASN-130, and there will be a competition between the RLGN and the ASN-130 to determine which system will be in the final version of the AV-8B. Figure 6.8 shows Honeywell's primary competition RLGs built by Litton that have a different form factor and a different concept in actual mechanization. Litton also has contracts with both the Navy and industry for RLG sensors and systems. It has been predicted that RLGs would be used in 50% of the inertial navigation systems by 1992.

6.4.6.2. **High-Resolution Radars, FLIRs.** Achievement of high-resolution radars and FLIRs is also being vigorously pursued. Radars should be able to achieve 10-foot resolution, which will allow some automatic target classification and identification techniques to work. Against ship-type targets, a very rapid discrimination between combatants and noncombatants is required.

6.4.6.3. **Voice Cueing and Synthesizers.** As discussed previously, voice cueing, voice synthesizers could cue the pilot to alert him to the proximity of way points. It could tell him what speed he should be flying for the particular flight path that he is on, warn him of obstructions, and in general just relieve him of some of his other duties and assist him in achieving more precise navigation.

6.4.6.4. **Integrated Systems.** It is felt by many avionics engineers that a better job of integrating equipment could be done, instead of the typical segmented black box approach. The Navy recently started a program with the Emerson Electric Company to tie their EC-153 radar to an RLG navigator to achieve improved radar and navigation performance. (See Figures 6.9 and 6.10.) This program is called LIASAR, which stands for Laser Inertial Aided Synthetic Aperture Radar. Emerson has modified the F-5 radar to make it coherent so that it can operate in a synthetic aperture mode. The Navy is providing the strap-down laser gyro navigation system to provide motion compensation for the radar.

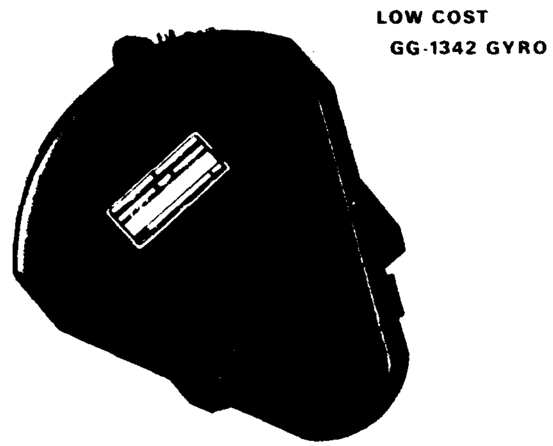

FIGURE 6.6. Honeywell Ring Laser Gyro.

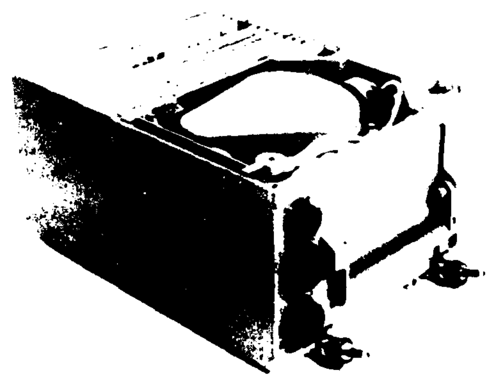

FIGURE 6.7. Inertial Navigation System With Ring Laser Gyro, Honeywell.

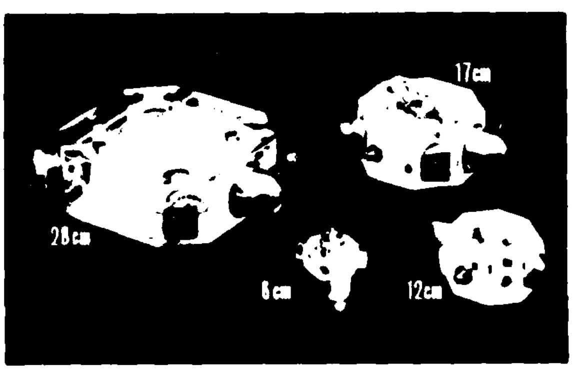

FIGURE 6.8. Litton Ring Laser Gyro.

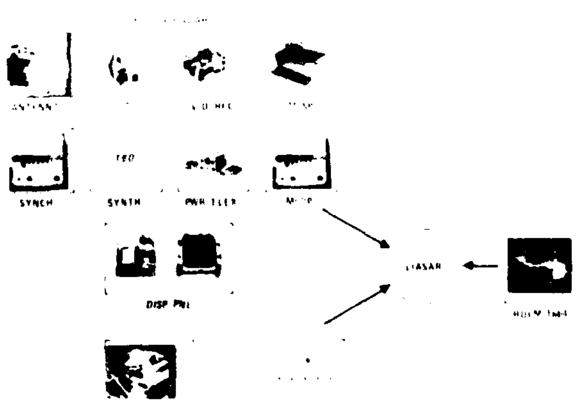

FIGURE 6.9. Laser Inertial Aided Synthetic Aperture Radar.

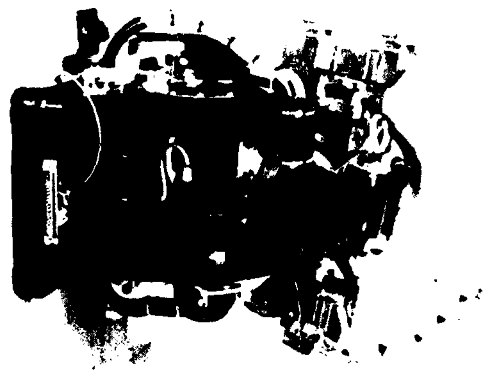

FIGURE 6.10. Laser Inertial Aided Synthetic Aperture Radar.

7. SURVIVAL TACTICS

Two primary tactics for survival in today's threat environment have been developed. The first tactic is to minimize exposure to enemy systems by low-altitude, high-speed ingress and egress, by flight path routing to avoid SAM sites, and by the use of EMCON techniques. In addition, both lethal and nonlethal defense suppression tactics will be employed.

The methods illustrated in Figure 7.1 by which targets are attacked are a compromise with survival tactics. Laydown is the most accurate delivery mode but it is also the most vulnerable to enemy defenses. Loft and pop-up tactics keep the aircraft at low altitude as long as possible. These tactics impose severe constraints on target acquisition and weapon delivery accuracy as well as exposing the aircraft to enemy defenses during the target acquisition and weapons delivery phases.

8. CONCLUSIONS

Our most critical deficiencies today are the lack of a standoff targeting and weapon delivery capability, the inability to effectively avoid and/or suppress enemy defenses, and, finally, the ever-increasing pilot work load resulting from the use of single-seat aircraft such as the A-7 and A-18. To fly low and fast through dense enemy defenses, acquire and attack the target, and return to the ship is stressing human capabilities to the limit. Development of automated procedures and pilot decision aids is mandatory if pilot work load is to be reduced to manageable dimensions.

Digital technology offers several ways to reduce pilot work load. We have the capability to provide the pilot precise navigation to an identification point. We have the ability to integrate the weapon delivery and flight control systems for free-fall weapons. We are developing several techniques for automatic target recognition. We need to map threat emitters onto the target scene displays and to provide the pilot with automatic flight path routing with real-time updates.

Overriding themes reoccurring in all the recent studies are the needs to insure the survivability of our own forces against enemy defenses, to provide offense in depth with quantity and quality, to make affordable systems, and, finally, to improve our command and control capability.

The main conclusion is that any future attack missions will face a dramatically increased ground threat that may seriously threaten not only the effectiveness of Navy attack missions, but also the ability of attacking forces to survive at all. There is no simple answer, but the solution will require the application of currently available technology and cooperative tactics in all areas.

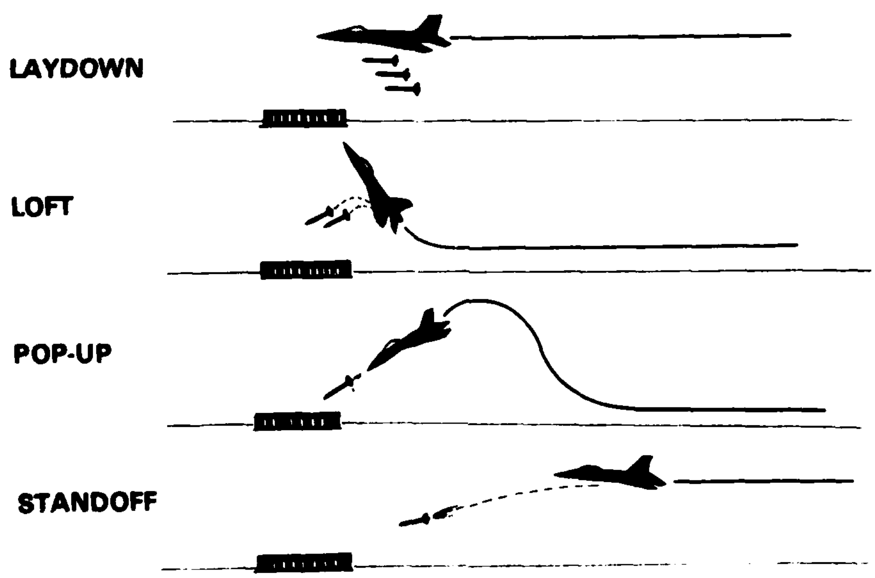

FIGURE 7.1. Weapon Delivery Tactics.

SYSTEME D'ARME D'UN AVION D'ATTAQUE FUTUR

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RESUME

L'utilité opérationnelle d'un avion d'attaque de faible volume, capable d'attaquer quelles que soient les conditions météorologiques, à faible altitude et grande vitesse, semble grande. Il apparaît que ce type d'avion devra disposer d'un très bon système de navigation, être préguidé sur ses objectifs et les acquérir à l'aide d'un radar fonctionnant à 94 GHz. La taille de cet avion impose un concept monoplace, donc la visualisation de toutes les informations nécessaires à l'attaque devra être faite dans le viseur.

L'augmentation constante du nombre des blindés et des systèmes de défense anti-aériens qui les protègent, amène à repenser la conception des avions d'attaque.

Actuellement, la tendance est à l'augmentation de la quantité des armements emportés et à l'augmentation de la probabilité de coup au but de chacun de ceux-ci. Sans qu'il soit remis en cause, ce principe paraît insuffisant, car l'avion porteur demeurera toujours confronté dans les mêmes conditions aux systèmes de défense anti-aériens qu'il rencontrera sur son parcours ; de ce fait, le taux d'attrition minimum risque de faire disparaître les avions porteurs avant que tous les armements aient été utilisés.

Il semble donc que l'avion d'attaque de moyen tonnage, tel qu'il est conçu aujourd'hui, doive être réservé à certains emplois spécifiques tels que :

- cibles de très grande valeur situées à grande distance,
- nombreuses cibles dans la profondeur du champ de bataille,
- affaiblissement de la défense adverse, afin de créer un environnement favorable à l'emploi d'un grand nombre d'avions d'attaque de plus petite taille.

Le présent exposé se limitera à ce dernier type d'appareil qui devrait, grâce à un coût beaucoup plus faible, pouvoir être produit en grande quantité et apporter ainsi une plus grande flexibilité d'emploi opérationnel.

Un avion d'attaque de faible tonnage n'offre qu'un volume restreint, en particulier pour l'électronique de bord. Aussi, malgré la très haute intégration des composants futurs, il ne faudra conserver que les fonctions strictement nécessaires, sinon le problème du refroidissement des circuits électroniques ne pourra pas être résolu.

Evoluant à proximité ou dans les domaines d'acquisition des systèmes de défense sol-air ennemis, cet avion devra évidemment disposer de signatures électromagnétique, infra-rouge et optique réduites. On peut constater à ce sujet, que de mauvaises conditions météorologiques, en particulier les brouillards, sont d'excellentes contre-mesures naturelles face aux conduites de tir infra-rouge et optiques et que les masques procurés par le relief sont des contre-mesures totales.

Il apparaît donc strictement nécessaire de doter cet avion d'attaque de fonctions lui permettant de disposer de toutes ces contre-mesures, c'est-à-dire lui permettant d'intervenir par mauvaises conditions météorologiques en utilisant les masques du relief.

Par suite du grand nombre de systèmes de défense sol-air, l'avion a une probabilité élevée de traverser les domaines de tir de certains de ces systèmes. Afin qu'il n'y demeure pas longtemps, il lui faut donc voler très bas et le plus vite possible.

On voit ici apparaître des exigences contraires, puisque le vol par mauvaises conditions météorologiques à grande vitesse et très basse altitude, s'il permet d'échapper aux systèmes d'arme sol-air, augmente notablement la probabilité de collision avec le sol, rend très difficile l'acquisition des objectifs et interdit l'engagement, sans risque très élevé, des objectifs d'opportunité.

Une solution au problème de la détection des cibles est peut-être de fournir en temps réel à cet avion d'attaque la position précise de ses objectifs ; il pourra alors les détecter, les acquérir, et obtenir les informations nécessaires au tir de son armement quand il arrivera à proximité de ceux-ci, quoiqu'il soit à faible altitude et à grande vitesse.

Le système d'arme de cet avions d'attaque disposerait donc des capacités suivantes :

- une capacité de pénétration du système de défense anti-aérien adverse par le vol en tous temps à une hauteur sol inférieure à 200 pieds et à une vitesse compatible de l'évitement des divers obstacles tels que relief, pylônes, haubans, câbles, arbres de grande taille, etc...
- une capacité de détection des cibles fixes telles que : ponts, centre de commandement, concentration de véhicules, de blindés, ... à une distance compatible de son altitude de vol, en utilisant une désignation de l'objectif issue d'un moyen aéroporté de détection à grande distance,

- une capacité de détection des cibles mobiles telles que blindés, artillerie auto-mouvante, camions, ... à une distance compatible de son altitude de vol, en utilisant une désignation de l'objectif issue d'un moyen aéroporté de détection à grande distance,

- une présentation synthétique au pilote de l'ensemble de ces informations afin que l'engagement des cibles soit effectué dans les meilleures conditions et, de ce fait, dans les délais les plus brefs après leur détection.

I. ESTIMATION DES CONDITIONS OPERATIONNELLES

1. Capacité de pénétration

La forte densité des systèmes de défense anti-aériens amène à considérer que l'avion pénétrera nécessairement dans leur domaine d'acquisition et de tir au cours de son vol vers l'objectif. Il est donc très difficile de déterminer de ce point de vue une altitude et une vitesse de vol optimum. La seule conclusion est qu'il est nécessaire de voler très bas, à grande vitesse et ceci même par mauvaises conditions météorologiques.

Ces considérations confrontées à l'exigence de l'anti-collision avec le relief, les pylônes, les câbles horizontaux et lignes à haute tension, les câbles verticaux avec ballon et les arbres de haute taille, amènent à estimer qu'une altitude minimum de vol par rapport au sol comprise entre 40 et 60 m peut être un optimum à condition de pouvoir détecter les câbles verticaux. En effet, cette altitude permet de survoler les câbles horizontaux et les lignes à haute tension dont la détection en tous temps quel que soit l'angle d'arrivée est très difficile et dont la densité en fait une menace importante.

Le vol de cet avion à environ 40 m d'altitude se heurtera à des obstacles de deux types :

- le relief, qui pourra présenter des développements verticaux importants (200 m à la verticale ; 1000 m avec une pente de 30° par exemple),

- les pylônes et les ballons avec câble qui peuvent présenter un développement vertical de 300 m.

2. Détection des cibles fixes

L'avion d'attaque est donc dirigé vers des coordonnées géographiques qui correspondent à l'objectif désigné. Cette information peut être fournie avec une excellente précision si elle est issue d'un fichier géographique, ou avec une précision un peu moins bonne, si elle est issue d'un système aéroporté de détection à grande distance utilisant, par exemple, un radar à antenne synthétique.

Quelle que soit l'origine on peut estimer que la précision de désignation sera meilleure que 100 m.

Son altitude de vol minimum étant pour des raisons de sécurité limitée à 40 m, la portée radioélectrique est limitée à environ 20 km, ce qui laisse supposer qu'étant donné les faibles angles d'incidences, l'identification de l'objectif ne sera pas possible au-delà de 10 km.

La détection de ces cibles peut donc être limitée à 10 km, ce qui demeure encore supérieur au domaine de tir de la plupart des défenses anti-aériennes qui les protègent.

3. *Détection des cibles mobiles*

L'avion d'attaque procède de la même manière que pour les cibles fixes, mais la détection va être rendue difficile par suite de l'imprécision de désignation liée à la vitesse du mobile et au vieillissement de la dernière information reçue à son sujet.

Estimant que le vieillissement de l'information ne sera pas supérieur à 1 mn et qu'une colonne de blindés peut se déplacer à une vitesse de 30 km/h (500 m/mn) environ, on constate que cette erreur de 500 m devient prépondérante sur l'erreur de localisation initiale.

4. Classification des cibles

Ce sujet est d'un très grand intérêt et doit faire l'objet d'études approfondies. Il ne sera cependant pas abordé dans le présent exposé.

II. SOLUTIONS ACTUELLES

1. Les avions d'attaque actuels sont autonomes et ils interviennent en utilisant des informations de localisation dont la précision est :

- bonne pour les objectifs fixes,

- mauvaise pour les objectifs mobiles par suite du vieillissement important de l'information initiale.

Leur système de navigation fournit une précision de l'ordre de 700 m en arrivant sur l'objectif.

La détection de ces cibles, de jour comme de nuit, est assurée à l'aide d'un ensemble de capteurs complémentaires tels que :

- caméra TV,

- caméra TV bas niveau de lumière,

- caméra infra-rouge (F.L.I.R.)

tandis que la télémétrie et le guidage de certaines armes sophistiquées font appel à des émissions laser.

Cette multiplicité de capteurs impose souvent des emports en container, ce qui diminue le nombre de points d'emport disponibles pour l'armement et exige souvent la présence d'un second membre d'équipage.

2. De plus, on constate que ce type de solution ne résoud pas le problème de la capacité tous temps, ni à fortiori celui de la pénétration à très basse altitude en tous temps. Une solution à cette dernière fonction est l'utilisation d'un radar fonctionnant en bande J qui, logé dans le nez de l'avion contraint pratiquement à loger les autres équipements en container ou dans des excroissances de fuselage préjudiciables à la surface équivalente radar de l'avion.

3. Pour ce qui concerne la capacité tous temps, il faut noter que les statistiques issues de relevés effectués dans l'Est de la France font état de :

. Brume durant toute la journée créant une visibilité inférieure à 2500 m	:	10 % de l'année
. Brouillard durant toute la journée créant une visibilité inférieure à 400 m	:	3 % de l'année
. Pluie d'intensité de 2 mm/h	:	2 % de l'année
. Pluie d'intensité de 10 mm/h	:	0,1 % de l'année

- Une pluie continue de 6 mm/h peut durer 2 heures,

- Une pluie continue de 12 mm/h peut durer 1 heure.

On constate donc que les conditions atmosphériques n'ont pas une influence marginale sur l'efficacité d'un tel avion d'attaque, car elles dégradent très fortement - en particulier les brumes et brouillards - l'efficacité des capteurs optiques et infra-rouge.

4. Il s'agit donc de rechercher une solution qui, ne nécessitant qu'un seul membre d'équipage et une quantité d'équipements faible, faciliterait la conception d'un avion de la classe 4 tonnes - hors armements - qui pourrait en tous temps intervenir avec de très bonnes chances de survie au-dessus du champ de bataille afin, hors de portée des défenses anti-aériennes rapprochées, de lancer des armements à guidage autonome mais de portée assez faible (anti-char, anti-radar, anti-ponts,...).

III. SOLUTION POSSIBLE

1. Considérations générales

. La contrainte issue de l'emploi en tous temps exclut les équipements utilisant des fréquences correspondant au visible et à l'infra-rouge, du fait de la très forte atténuation provoquée par le brouillard et les fumées du champ de bataille ; brouillards qui sévissent fréquemment et durant de longues périodes comme cela a été dit précédemment.

. Limiter cet avion à la classe des 4 tonnes de masse au décollage hors armement, c'est limiter le maître-couple du nez de l'avion à une taille telle que l'antenne d'un radar qui y serait implantée ne pourrait pas dépasser 30 cm et que le volume global disponible ne serait pas supérieur à 70 litres.

. Il s'agirait donc de concevoir un équipement qui aurait une portée moyenne de 10 km sur des objectifs fixes et mobiles tels que char, centre de commandement, ponts,... et qui assurerait un suivi de terrain à une altitude comprise entre 120 et 200 pieds, à une vitesse de l'ordre de 300 m/s.

Suivi de terrain

On a pu constater que l'altitude de vol retenue permet de classer les obstacles en deux groupes :

- relief,
- superstructures à développement vertical maximum de 300 m.

Il peut être envisagé d'assurer le suivi du relief d'une manière prédictive si l'on dispose à bord de l'avion d'un fichier du terrain survolé et si le système de navigation est suffisamment précis. Ce fichier doit être adapté à un vol d'une durée inférieure à l'heure.

Estimant qu'un système de navigation inertie-doppler avec recalage automatique altimétrique et de surface doit permettre d'obtenir une précision de l'ordre de 50 m, on peut constater qu'un moyen prédictif se révèle suffisant pour assurer l'évitement du relief.

Pour ce qui concerne les superstructures à développement vertical, en particulier les barrages de ballons avec câbles, il est certain que le suivi de relief prédictif est inadapté. Il est donc

nécessaire de disposer d'un capteur permettant l'évitement de ce type d'obstacles imprévus, et ceci même par mauvaises conditions météorologiques.

Afin que cet évitement, qui peut aussi être envisagé dans le plan horizontal dans certains cas, puisse se faire en toute sécurité, il faut réduire l'imprécision sur l'orientation du vecteur vitesse sol afin que le capteur analyse bien les obstacles situés dans le plan vertical contenant ce vecteur vitesse. Il semble qu'une des meilleures solutions au plan de la sécurité soit de faire mesurer les composantes V_x, V_y, V_z de ce vecteur à l'aide du capteur lui-même.

Ce dernier problème étant supposé résolu, on peut estimer que la surveillance d'un secteur angulaire de 50 mrd tout au long de la route avion est suffisante, puisque cela assure pour une portée minimum de 2000 m, la surveillance d'un couloir de 100 m de large ; ceci couvre en particulier le risque lié à l'imprécision du système de navigation.

Détection des cibles

On constate que si la précision du système de navigation est de l'ordre de 50 m, cela se traduit par une imprécision de désignation angulaire qui peut atteindre :

. pour les cibles fixes : 15 mrd à 10 km
38 mrd à 4 km

. pour les cibles mobiles : 55 mrd à 10 km
138 mrd à 4 km

2. Projet de capteur

1. Détection des échos mobiles

Les véhicules de combat se déplacent :

- soit en convois lors des concentrations et leur vitesse est de l'ordre de 30 km/h,

- soit à des allures très variables de l'ordre de 4 à 30 km/h selon le terrain et le moment, lors des phases d'engagement.

. Il est donc nécessaire, si l'on utilise une technique doppler, que l'ambiguïté de vitesse ou la zone de vitesse aveugle soit repoussée au-delà de 50 km/h (14 m/s) ce qui crée une contrainte sur la fréquence de répétition de l'énergie émise :

$$\frac{2.14}{3.10^8} \times fe \leqslant fr$$

où fe est la fréquence d'émission et fr est la fréquence de récurrence.

Il faut de plus que l'ambiguïté de distance soit repoussée au-delà de la distance de détection qui, on l'a vue, a été fixée à 10 km.

$$\frac{C.Ts}{2} = \frac{3.10^8}{2} \times \frac{1}{fr} \geqslant 15\,000 \text{ d'où } fr \leqslant 10 \text{ kHz}$$

de la première inégalité on peut donc conclure que :

$$fe \leqslant fr \times \frac{3.10^8}{2.14} \qquad \boxed{fe \leqslant 100 \text{ GHz}}$$

. Pour ce qui concerne la détection des vitesse faibles, il faut que le spectre de l'énergie rétrodiffusée par le sol soit aussi faible que possible. Ceci sera le cas si le faisceau rayonné est de faible largeur.

Tenant compte du fait que la recherche de la cible doit se faire sur environ ± 88 mrd par suite de l'erreur initiale de localisation, on peut écrire.

$$\Delta fd_s = \frac{2.V_s \,.\, fe}{C.} \,.\, \sin\theta \,.\, \Delta\theta$$

Δfd_s étant le spectre de l'énergie rétrodiffusée par le sol.

Comme Δfd_s doit être nettement inférieur au glissement de fréquence doppler associé à la vitesse minimale qui doit être détectée : à 4 km/h (1,1 m/s), nous avons l'inégalité :

$$3 \times \frac{2\,V_s}{C} fe \times \sin\theta \times \Delta\theta < \frac{2}{C} fe \times 1,1 \quad \text{soit } \Delta\theta < \frac{1,1}{\sin\theta \,.\, V_s .3}$$

pour V_s : 275 m/s et θ = 95 mrd, on déduit :

$$\Delta\theta < 14 \text{ mrd}$$

Pour une antenne dont le diamètre est de 30 cm, cela implique l'utilisation d'une fréquence d'émission fe issue du calcul suivant :

$$\frac{70\lambda}{d} < \Delta\theta$$

$$\boxed{fe > 87 \text{ GHz}}$$

. Ces cibles mobiles doivent être détectées jusqu'à une portée de 10 km en tous temps.

Les contraintes de volume et de refroidissement impliquent a priori l'emploi d'une puissance pas trop élevée, aussi faut-il tenir compte de l'atténuation apportée par l'atmosphère, par les brouillards et par les précipitations.

On constate que dans la bande de fréquence de 13 GHz résultant des considérations précédemment exposées, une bande de 3 GHz centrée sur 94 GHz présente des atténuations beaucoup plus faibles.

On note que cette bande présente les atténuations suivantes : (1)

- 0,4 dB/km dû à l'atmosphère.
- 0,5 dB/km lors de brouillards réduisant la visibilité à 100 m, ce qui correspond à des gouttelettes d'environ 35 μ (il faut noter que l'infra-rouge présente alors une atténuation de l'ordre de 90 dB/km).
- 0,95 dB/km pour des pluies de 1 mm/heure avec des gouttes inférieures à 1000 μ en moyenne.
- 2 dB/km pour des pluies de 4 mm/heure avec des gouttes inférieures à 1500 μ en moyenne.
- 5 dB/km pour des pluies de 10 mm/heure.
- 9 dB/km pour des pluies de 16 mm/heure avec des gouttes inférieures à 3000 μ en moyenne.

L'atténuation créée par de fortes pluies est évidemment prohibitive, mais il faut noter que la probabilité de rencontrer ces pluies en Europe est assez faible. Les statistiques précisent en effet que *les probabilités de précipitations sont de l'ordre de :*

- 2.10^{-4} pour des précipitations de 20 mm/h,
- 1.10^{-3} pour des précipitations de 10 mm/h,
- 2.10^{-2} pour des précipitations de 2 mm/h,

contre

- 2.10^{-2} pour des brouillards réduisant la visibilité à 100 m durant 24 heures.

Si la détection se fait à l'aide d'un traitement donnant un taux de visibilité T_v = 20 dB sur le clutter de sol, on obtient une portée fonction de la puissance crête selon la relation suivante :

$$P_c = \frac{D^3.\,(4\pi)^3.L.kTo.F\,(^E/b).T_v.e^{2\alpha D}}{G^2.\,\lambda^2.\,\tau^2.\,\theta.\,^C/2.\,\sigma o}$$

soit avec :

$L = 13$ dB $kT_o = -204$ dB $F = 10$ dB $(^E/b) = 40$ dB $T_v = -20$ dB

$G^2 = 98$ dB $\lambda^2 = -50$ dB $\tau^2 = -140$ dB $\theta = -19$ dB $^C/2 = 82$ dB

$\sigma_o = -10$ dB

$$P_c = -89 + 30\log D_m + 2.a.D_{km} \quad \text{(figure 1)}$$

avec a = l'atténuation par kilomètre de portée.

Le développement actuel des tubes de puissance permet d'espérer pouvoir disposer d'un émetteur de 3 kW de puissance crête délivrant une onde cohérente à 95 GHz.

Ceci permettrait d'obtenir une portée de 6 km en présence de brouillard et de pluies ayant une densité inférieure ou égale à 2 mm/h. Pour des pluies plus importantes (6 mm/h) la portée serait réduite à 3,5 km. Ces valeurs sont insuffisantes.

Il faut donc envisager d'utiliser des techniques telles que la compression d'impulsion avec un taux de l'ordre de 50 afin d'obtenir une portée de l'ordre de 10 km au lieu des 6 km précédents.

2. Détection des cibles fixes

. Le char est la cible dont la surface équivalente radar est la plus faible ; elle peut être estimée à 100 m^2 pour les fréquences concernées.

Afin de pouvoir détecter cette cible sur un fond de clutter de sol, il est nécessaire de réduire la cellule élémentaire de sol à 10 m^2 au maximum. Ce qui signifie que :

$$\sigma_s = \frac{\theta . D . \tau . C}{2} . \sigma_o \leqslant 10 \text{ m}^2$$

implique pour un sol ayant un σ_o de - 10 dB, une largeur d'impulsion :

$$\tau \leqslant 5{,}13.10^{-5} \times D^{-1}$$

soit pour une portée de 10 km $\tau \leqslant 5$ ns

Ceci offre une cellule élémentaire de 65 m par 0,75 m à 5000 m, ce qui n'est pas sans intérêt au plan de l'identification.

. Tenant compte du fait que la fréquence de répétition est de 10 kHz, si la vitesse de balayage de l'antenne est de 15 °/s, le nombre d'impulsions intégrables est de :

$$\frac{0{,}6}{15} . 10^4 = 400$$

ce qui permet de disposer d'un gain de post-intégration cohérente de l'ordre de 20 dB.

La puissance crête nécessaire est dans ces conditions :

$$P_c = \frac{D^3 . (4\pi)^3 . L . F . kT_o . (E/b) . N . e^{2\alpha D}}{G^2 . \lambda^2 . \tau^2 . \theta . C/2 . \sigma_o}$$

soit avec :

$N = -20$ dB $\quad \tau^2 = -166$ dB $\quad \sigma_o = -10$ dB $\quad (E/b) = 40$ dB

$$P_c = -63 + 30 \log D \text{ (m)} + 2.a.D \text{ (km)} \qquad \text{(figure 2)}$$

avec a = atténuation par kilomètre de portée.

On constate qu'en présence de brouillard, la portée n'est que de 1,5 km, ce qui est insuffisant.

Il est donc là encore nécessaire de recourir à la compression d'impulsion avec un taux de l'ordre de 1000 afin d'obtenir une portée de 9 km dans des conditions atmosphériques identiques.

On note que malgré tout, par fortes pluies, la portée sur un char immobile sera très faible et que le pilote aura peu de temps pour identifier et engager la cible.

. La détection des cibles fixes s'intéresse aussi à des cibles de très forte surface équivalente radar, telles que des ponts, des centrales électriques, etc.... La surface équivalente peut alors atteindre 10 000 m^2 et la portée en présence de brouillard peut atteindre plus de 20 km, c'est-à-dire se situer au-delà de l'ambiguïté en distance.

Ce problème est cependant aisément résolu de diverses manières.

. On peut donc conclure que cette fonction permet de détecter, d'identifier et d'engager des cibles fixes à des distances supérieures à la portée efficace des systèmes de défense rapprochée sol-air même par mauvaises conditions météorologiques.

3. Suivi de terrain

. L'analyse du relief et des obstacles doit être effectuée dans un secteur 50 mrd centré sur le plan vertical passant par le vecteur vitesse sol. Ceci signifie que le faisceau ayant une largeur de 13 mrd, il faudra balayer alternativement 4 secteurs angulaires verticaux et adjacents.

. Pour un vol à une altitude de 40 mètres et à une vitesse de 300 m/s, si la portée de détection est de 10 km, le temps de renouvellement des informations devrait être de l'ordre de 2 secondes pour qu'un évitement dans le plan vertical soit possible dans de bonnes conditions de vol.

Si le secteur angulaire couvert en site est de l'ordre de 40°, chaque balayage élémentaire durant 0,5 s, la vitesse de balayage doit être de 80°/s.

. La hauteur de vol choisie étant comprise entre 40 et 60 m, il apparaît que la mesure de la distance doit être faite avec une précision de l'ordre de 10 m. Il faut donc limiter la largeur d'impulsion à 50 ns.

. La portée dans ces conditions est donnée par la relation :

$$D^3 = \frac{P_c . \tau . G^2 . \lambda^2 . \theta . \varepsilon . {}^{c}/2 . \sigma_o . N}{(4\pi)^3 \; L.F.kT_o . ({}^{E}/b) . e^{2\alpha D}}$$

soit avec $\sigma_o = -30$ dB, $N = 15$ dB et ${}^{E}/b = 10$ dB

. $10 \log D^3 = 122 - 2.a.D$ (km) (figure 3)

On constate que les portées obtenues paraissent suffisantes, d'autant que le calcul s'appuie sur un σ_o de - 30 dB ce qui est pessimiste puisque le relief le plus dangereux dans le cas d'une imprécision de la navigation, sera celui présentant de fortes pentes.

. Le second type d'obstacles concerné est le câble vertical, le pylône et ses haubans.

Si l'on admet que de tels câbles présentent une surface équivalente radar de 0,5 m^2 à 95 GHz, la portée est donnée par la relation suivante :

$$D^4 = \frac{P_c . \tau . G^2 . \lambda^2 . \sigma_c . N}{(4\pi)^3 . L . F . kT_o . ({}^{E}/b) e^{2\alpha D}}$$

avec $\sigma_c = -3$ dB, soit :

$10 \text{ lot } D^4 = 160 - 2.a.D$ (km) (figure 3)

On constate que les portées obtenues sont constamment supérieures à celles obtenues sur un sol de - 30 dB.

. La portée sur les câbles considérés est donc toujours supérieure à 1500 m, même pour de très mauvaises conditions atmosphériques.

On vérifie que cette portée est suffisante pour éviter dans le plan horizontal un câble vertical.

. Afin d'éviter que l'avion ne se dégage de la protection du sol par suite de fausses alarmes telles que celles créées par de fortes précipitations, il faut éliminer les échos créés par ces dernières.

Le rapport des puissances rétrodiffusées par la pluie et l'obstacle s'écrit :

$$\frac{P \text{ obstacle}}{P \text{ pluie}} = \frac{\sigma \text{ obs.}}{\theta^2 . {}^{C}/2 . \tau . D^2 . \eta}$$

avec n coefficient de rétrodiffusion de la pluie

$\eta = 10^{-3}$ pour 16 mm/h (2)

$\eta = 6.10^{-4}$ pour 10 mm/h (2)

On constate que sans traitement particulier l'écho d'une précipitation de 16 mm/h est de même niveau que l'écho d'un câble pour :

$$D \text{ (dB)} = \frac{1}{2} (-17{,}3 - \tau \text{ (dB)})$$

soit :
D = 1920 m pour = 5 ns
D = 1360 m pour = 10 ns
D = 610 m pour = 50 ns

Il apparaît donc que si une largeur d'impulsion de 50 ns est adaptée à la détection des échos de sol, elle ne l'est pas s'il s'agit d'affaiblir les échos de pluie.

Les mesures effectuées sur les spectres de pluie (3) permettent de constater que le temps de décorrélation est de l'ordre de 4 ms, alors que l'obstacle que l'on veut détecter dans la précipitation a un temps de décorrélation plutôt de l'ordre de 30 ms. Un gain de traitement de 8 dB est donc possible, ce qui permettrait la détection de l'écho de câble malgré une pluie de 16 mm/h à une distance de l'ordre de 1920 mètres avec $\tau = 5$ ns.

Cette performance est juste suffisante, mais il faut observer que ce type de précipitation est peu fréquent et de courte durée dans l'Est de la France.

. On peut aussi observer que grâce aux balayages successifs de 4 secteurs angulaires verticaux, le radar est à même de discriminer un obstacle large, comme l'est le relief, d'un obstacle étroit comme l'est un pylône ou un câble vertical.

Il est donc possible d'envisager des évitements dans le plan horizontal afin d'éviter à l'avion de se dégager du relief, ce qui est justement l'objectif de la mise en place de câbles verticaux soutenus par des ballons.

4. Conclusion partielle

. Il apparaît donc qu'un radar fonctionnant à 94 GHz doit être à même d'assurer avec une probabilité très élevée vis-à-vis des diverses conditions atmosphériques possibles dans l'Est de la France, les trois fonctions air-sol principales que sont :

- la détection des chars en mouvement et des autres cibles mobiles avec une portée de l'ordre de 10 km en présence de brouillards réduisant la visibilité à 100 m,

- la détection des chars et autres cibles de même type immobiles, ainsi que celles des ponts, centres de commandement, etc... à une distance minimale de 9 km en présence de brouillards réduisant la visibilité à 100 m,

- le suivi de terrain à une vitesse sol de 300 m/s et 40 m du sol grâce à une détection suffisamment lointaine du relief et des câbles verticaux, et à une connaissance précise de la direction et du module du vecteur vitesse tout au long du vol.

Pour cela les hypothèses suivantes ont été supposées réalistes :

- utilisation d'un émetteur cohérent de 3 kW de puissance crête utilisant un facteur de forme de 20,

- utilisation d'un récepteur à compression d'impulsion,

- utilisation de composants hyperfréquences et d'un radôme dont les pertes globales sont d'environ 10 dB.

5. Intégration de ce radar dans le système

. Outre les fonctions air-sol précédemment citées, on note que la fonction cartographique peut donner une cellule élémentaire de l'ordre de 0,75 x 65 m à une distance de 5 000 m.

En utilisant la technique de la corrélation automatique sur une zone entourant un point de recalage prévu, on peut estimer qu'un recalage de position avec une précision de l'ordre de 20 m est possible sans intervention humaine particulière.

Une redondance très utile peut être ajoutée sans addition notable de circuits en utilisant les informations issues de la radio-sonde pour effectuer un recalage automatique de position par corrélation altimétrique.

. Pour des raisons de sécurité en suivi de terrain, il a été jugé utile de mesurer le vecteur vitesse sol à l'aide de ce radar. Cette information continue tout au long du vol vers l'objectif doit être utilisée afin de corriger le concert avec les recalages successifs de position, les dérives de la plate-forme inertielle.

. On obtient ainsi un système de navigation qui outre sa grande précision, offre un grand nombre de modes dégradés en cas de panne, sans pour cela multiplier le nombre des équipements.

. Le pilote doit donc être à même de se rendre avec une grande précision de navigation vers la zone où des objectif lui sont désignés. Le système devra déterminer l'instant à partir duquel, la probabilité de détection des objectifs étant très grande, l'avion devra poursuivre son vol en suivi de terrain prédictif avec surveillance par la corrélation altimétrique, tandis que le pilote identifiera les objectifs détectés par le radar, les assignera à ses divers armements et effectuera le tir.

. Le système décrétant l'instant optimum où le radar va passer en fonction détection des cibles fixes et mobiles, il est important que le pilote qui jusqu'alors travaillait principalement à l'aide de la visualisation tête haute, s'y prépare et que la transition ne soit pas trop brutale. On peut donc envisager de lui présenter en tête haute à l'aide du fichier de terrain servant aux recalages de position automatique, une représentation synthétique de ce relief sur laquelle seraient superposés les obstacles vus par le radar en fonction suivi de terrain.

La décision de commutation étant liée à un problème de visibilité radio-électrique, donc fort probablement au survol d'une crête, la présentation synthétique du relief faciliterait la compréhension par le pilote de l'annonce par le système de la prochaine commutation.

Le positionnement en tête haute des objectifs pré-désignés pourrait aussi se faire, facilitant ainsi une éventuelle identification optique de l'objectif lorsque la visibilité le permet.

Sinon, le pilote passerait en tête basse afin d'identifier l'apparition d'un écho ou des échos à proximité de la prédésignation, tout en conservant en tête haute une idée du relief qui l'environne et sur lequel le suivi de terrain prédictif s'exerce.

. Le tir ayant été effectué, les armements étant supposés autonomes, le radar devra repasser en suivi de terrain afin que l'avion retrouve la sécurité face aux obstacles tels que câbles, haubans et pylônes.

. Il y a là évidemment une période où la sécurité est nettement dégradée puisque, outre le fait que le radar n'est plus en fonction suivi de terrain, le pilote doit identifier sur son écran radar les objectifs annoncés, les affecter à son armement et tirer celui-ci ; mais on peut aussi noter que cette dégradation est sûrement de plusieurs ordres de grandeur inférieure à celle liée à l'approche à environ 5 000 m d'objectifs souvent fortement défendus.

6. Conclusion

Le présent exposé avait pour but de présenter une hypothèse de système d'arme air-sol quasiment tous temps, adaptable à un avion monoplace dont la masse hors armement serait de l'ordre de 4 tonnes.

Il apparaît que ce système exige une prédésignation précise des objectifs et qu'il peut ensuite remplir sa mission avec de bonnes chances de succès de jour comme de nuit, par brouillards divers et précipitations relativement importantes, conditions qui couvrent 99 % des cas d'emploi.

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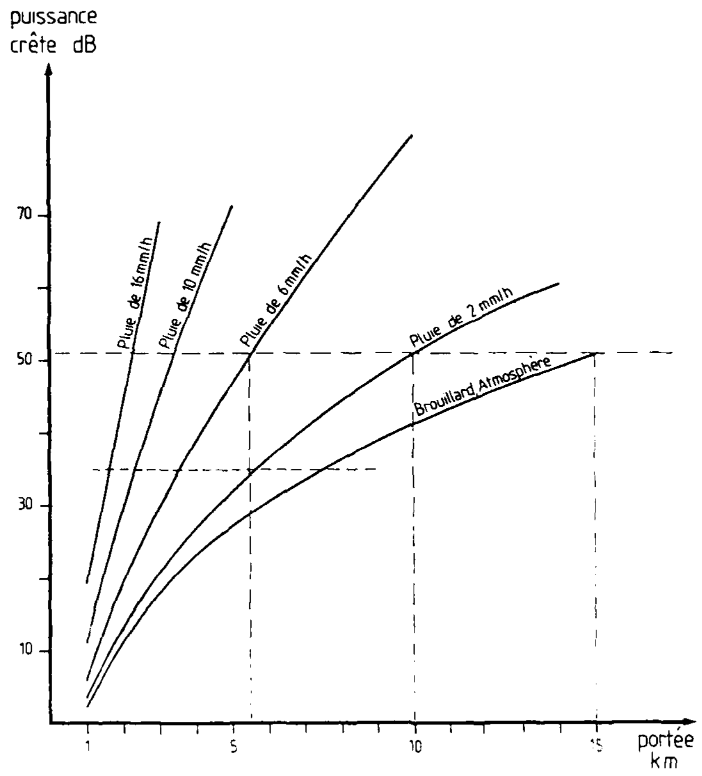

FIGURE 1 : Portée sur cibles mobiles

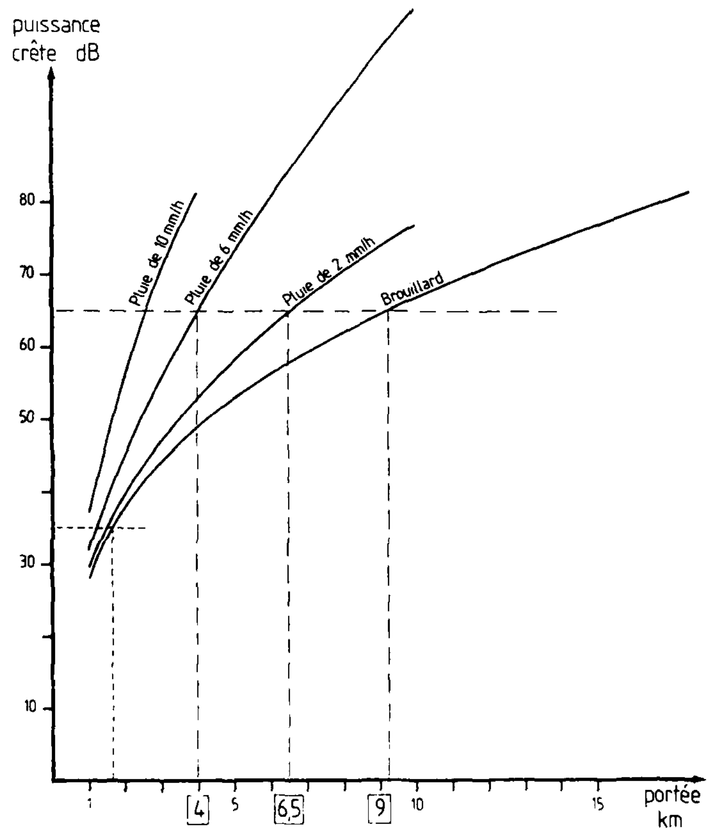

FIGURE 2 : Portée sur cibles fixes telles que des chars

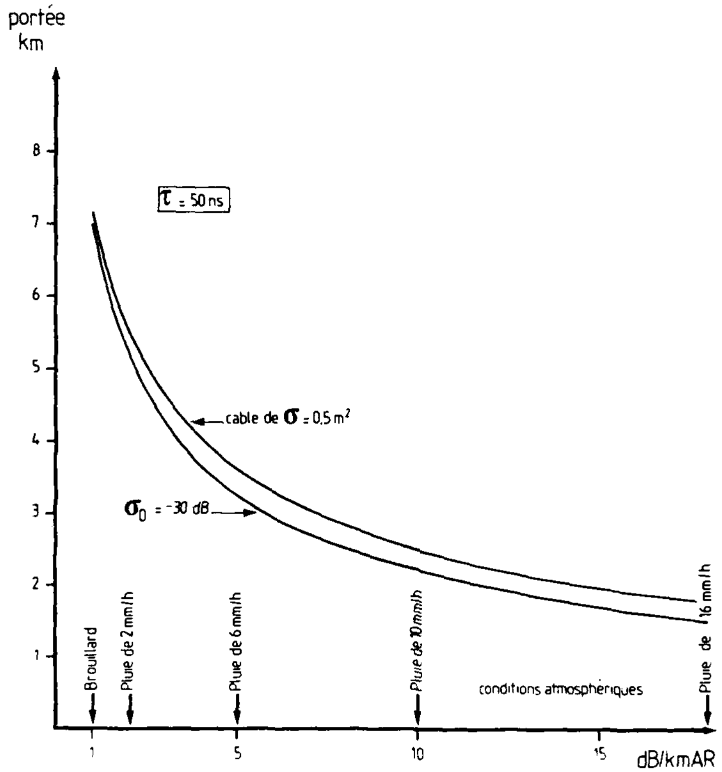

FIGURE 3 : Portée en Suivi de Terrain selon les conditions atmosphériques.

ADVANCED TECHNOLOGY AND FIGHTER COCKPIT DESIGN - WHICH DRIVES WHICH?

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SUMMARY

The increasing requirements of the modern ground attack fighter-bomber in the European theatre result in continuous pressure on the cockpit designer to optimise the man-machine interface by all means available to him.

Fortunately, there are developments in Avionics which, though by some are looked upon as revolutionary, must become an essential part of the evolutionary process which an aircraft undergoes in its realisation of these requirements. The developments are sometimes driven directly by the needs of the designer, sometimes introduced to the aircraft from the broader technological base of the Electronics Industry as a whole.

This paper sets out to illustrate that, with this ever-increasing requirement on the aircraft evolving from the expected battlefield environment, three important topics of development to improve the crew interface in the Ground Attack Phase are Automation, Synthetic Speech and Direct Voice Input, the latter being seen as a major contribution necessary to simplify an already severe control task.

1. INTRODUCTION

There have been significant technological changes in the last ten years, both inside and outside the Aircraft Industry. The advent of more powerful processors, data transmission systems and sensors not only provides us with the ability to produce a more capable aircraft, but also allows us to ease some of the crew workload problems by total or partial automation of predictable tasks, at the same time allowing better access, on demand, to detailed information within the system. The crew is thus released to concentrate on those activities which, by necessity, must be based on unpredicted information experienced on the mission.

The development of logic switching and minimum displacement controls, replacing their power and mechanical equivalents, will minimise motion required for control. The resulting gains in cockpit space and improvements in control positions can greatly enhance the pilot's task. The effect of extending the use of colour in the cockpit by the introduction of colour Cathode Ray Tube (CRT) Displays, has received considerable attention in recent years and only awaits the technology for its fuller exploitation. The requirement to keep head-up during low level flying has stimulated development of Head-Up Displays (HUD) and focused attention on ensuring that all necessary controls are located on and near either throttle or stick.

All these developments are seen as ways of enhancing the crew's performance over the whole mission in general. In particular however, probably the highest workload and stress situation exists in the Ground Attack Phase and it is here that innovation can reap the greatest rewards.

2. THE GROUND ATTACK PROBLEM

The difficulty in delivering a weapon on a target is a function of many parameters, for example;

- Knowledge of target position
- Type of target
- Local terrain
- Local ground defences
- Importance of undetected ingress and egress
- Type of weapon to be delivered
- Weather

Considering one of the easier attacks (Fig. 1), the planned attack with retarded stores, that is, the deep penetration interdiction role, there may be six seconds available for aiming and tracking, initial acquisition being required up to ten seconds from a target on which a pilot has been well briefed. This must be regarded as a rare luxury over the battlefield where, in contrast, even searching a pre-specified area of enemy-occupied territory, it is more likely that acquisition, recognition, identification and tracking of a target of opportunity all have to be carried out in the space of between two and four seconds, culminating in a manual release of the weapon or weapons.

Throughout the attack it is likely that the aircraft will be required to fly low and fast for survival, making full use of terrain screening from enemy radar. Although low level delivery considerably reduces target sightline rate at release, thus tending to ease the pilot's problems of release point definition, it also minimises acquisition range and intensifies the flying task. The very act of flying current aircraft safely in these conditions can raise stress considerably in that pilot workload, already high from the above activities, is increased further by the need to cross-monitor single-sourced information on the Head-Up Display with the Head-Down instruments; for example, such parameters as attitude, height and height rate.

Current warning systems attract the pilot's attention by a master warning, usually in the form of flashing red lights or "Attention Getters" within the pilot's field of view, and sometimes accompanied by an audio tone. The pilot, having cancelled the master warning, has then the option, depending on his workload at that time, of either trying to identify the source of trouble by referring to his central warning panel and system displays, or to ignore the problem until his current workload has reduced. It may be said that the level of manual cross-monitoring during battlefield engagement is reduced to a minimum. The inherently compelling nature of the master warnings, however, will either increase stress considerably if they are just cancelled or increase stress and workload if they are cancelled and an attempt made to diagnose, requiring some Head-Down activity in the process.

All these factors contribute to the pilot's difficulties in aiming and tracking the target and to make matters worse, the target sightline grazing angle is low at weapon release, resulting in a high impact point sensitivity to pilot aiming error (Fig. 2). It is, therefore, little wonder that pilot aiming error contributes the largest portion of the total bombing error in this type of attack.

In summary, time is short, the aiming and tracking task is not easy and, by the time a release solution is achieved, stress and possibly fatigue are high.

3. POSSIBLE SOLUTIONS

Major problem areas which come out of the above discussion are dependent on the characteristics of the weapons used, the sensors used and the nature of the crew interface. For example, referring to Fig. 2 again, an increase in the sightline grazing angle will, on the face of it, seem to be the solution to reducing the sensitivity of pilot aiming error. This can be achieved by increasing the drag coefficient of the retarded store, thus reducing the forward throw. The benefits in the bombing error analysis are manyfold in that the sensitivities of angular errors from other sources are reduced, for example the HUD, Inertial Platform, Windscreen and Range Sensor.

For any given bomb, there are other ways of increasing sightline grazing angle such as reducing speed or increasing height, but vulnerability problems again creep in and other detrimental factors in the overall error analysis begin to take effect.

Alternatively, on the weapons front, the use of more sophisticated stores such as Laser Guided Bombs will ease the problem, though this example requires the presence of a Forward Air Controller or on-board laser designator and an increase in height may be required for their delivery. Whether guided by laser or completely post-launch autonomous, intelligent weapons developed to increase hit probability must, at the same time, be designed to reduce pilot workload in their development.

The continuing development of sensors remains an essential part of future avionic research programmes. Not only must attention be given to sensors and facilities which increase time available for acquisition, recognition and identification, such as Doppler Beam Sharpening, Synthetic Aperture Radar and the Helmet Mounted Sight (HMS), but also to those which ease the flying task and extend the vehicle's night/all weather capability, such as Terrain Following/Terrain Avoidance and Low Light Television.

Other papers give more detail on the specific subjects of sensors and weapons, and we now concentrate on the possibilities of alleviating crew workload in the task as illustrated, by direct application to the cockpit.

4. CREW INTERFACE ENHANCEMENT

The battle scenario calls for a lightweight, highly manoeuvrable fighter-bomber with low infra-red and radar signatures, capable of operating at high speed, low level, in an ECM environment. It must have night/all weather capability with growth potential to accommodate new sensors and weapons.

Part of this requirement dictates a small, single seat aircraft which will then result in an ever-increasing man-machine interface being squeezed into an ever-diminishing cockpit.

4.1 The Head-Down CRT

The space available for controls and displays is scarce, to say the least. In recent years, the realisation of the need has introduced multifunction displays, CRTs being the only surface then available for this purpose. This has driven the development of brighter CRTs for wider use in successive aircraft. The extension of this work into the realms of colour is already evident in more recent Civil Aircraft and it is expected

that in the near future, the greater step towards meeting the rather severe military requirements in vibration and ambient illumination will be taken.

In conjunction with CRT development, the use of Multifunction Keyboards (MFK) has spread, allowing interaction with the systems. Providing care is taken in avoiding excessive use of sequential menus with their attendant inaccessibility, the MFK is a powerful device in minimising the requirement for panel space.

A further exploitation of the CRT is found in the development of the Touch-Sensitive Display. Typical applications which have been investigated at BAe Warton on the Marconi Digilux system are fuel management, mission planning and systems control. For instance, a pictorial display of the fuel system (Fig. 3) can be presented showing total fuel and individual tank contents, allowing change by touch of crossfeed valve, fuselage tank transfer valve and emergency transfer valve. The space gains in this method of multi-moding a display surface are augmented by the ergonomic advantages and the increase in system detail readily available to the pilot. The all-important simplicity of operation is a desirable feature in minimising crew training requirements.

4.2 Side-Console Line-Replaceable Units (SCLRU)

An innovation applied to Civil aircraft in the 1950's was the SCLRU, at the time seen as advantageous ergonomically. Now, the widespread adoption of the MIL-STD-1553B Data Bus throughout the modern aircraft, having reduced the wiring and hence reduced the weight, having reduced the number of pin breaks and hence increased reliability, is being extended into the cockpit with the application of SCLRU's, adding to the ergonomic gains (Fig. 4). Instead of each control panel either containing the associated equipment or being a sub-unit of its' equipment hard-wire linked together, functionally grouped controls and displays on the side consoles and quarter panels interface with the Avionics Bus, almost eliminating power switching from the cockpit. Apart from the usual data bus gains mentioned above, use of panel area is optimised and the improved ergonomic interface realised.

4.3 Keeping Head-Up

The topics mentioned above have been concerned primarily with items inside the cockpit, requiring head-down operation to a greater or lesser extent. In the context of a complete mission they all play their rightful role and are essential developments for the modern fighter-bomber. The emphasis for the Attack Phase, however, must be on keeping the pilot's head out of the cockpit in the interests of safety, vigilance and the demanding weapon aiming task outlined earlier. This leads us to seek ways of improving the communication links between pilot and system, perhaps even changing their form.

INTEGRITY OF HUD DATA: The first task to look at is to improve the integrity of the safety-critical parameters displayed on the HUD in order that the pilot is not tempted to cross-monitor with head-down information. The importance of this work has resulted in a study at BAe Warton to investigate display system architecture with a view to enhancing availability and integrity of information presented to the pilot, both head-up and head-down. This engineering study is on-going in collaboration with Marconi Avionics, Smiths Industries and Ferranti.

The problem of integrity starts at the source of the parameter. For example, in the case of attitude (Fig. 5), one approach is to install two Inertial Platforms and, by cross-monitoring automatically with a third source of information from rate and acceleration sensors, perhaps those embedded in the Flight Control System, achieve the required level of integrity without the inherent loss of availability associated with a dual system

Using the Avionics Data Bus, best information is then exported to the Displays Suite, in which the weak link lies in the waveform generation/processing unit which drives the CRT. Again, a triplex system with automatic cross-monitoring is the only sure way to meet the requirement. Any head-down attitude recovery display would then use the same source of basic data and obviate manual cross-monitoring.

With regard to the amount of information on the HUD, the development of the wide-angle displays now being made available to us with the application of diffractive optics, may allow more parameters within the pilot's vision head-up and the increased area used for such items as warning information or engine data.

HMS: These improvements in HUD systems can be augmented by use of the HMS. Trials with a Honeywell equipment have been carried out at BAe Warton using a development Jaguar aircraft, confirming the already established advantages of the equipment, that is;

- an extension to the HUD field of view for acquisition/designation of airborne targets, resulting in considerable time-saving in missile acquisition and release,

- the ability to display safety-critical data, allowing the freedom of all-round search with less frequent reference to cockpit instruments for the flying task.

In addition, a method of position fixing off-track targets to facilitate second pass attacks was investigated. This trial successfully developed the software and verified the practicality of the method.

Caution is required in optimising the joint use of these two primary displays, taking care on the one hand to avoid the manifestation of the too familiar cluttered display, and on the other ensuring a careful balance between them. The philosophy of moding by phase of flight is an important technique to help avoid the clutter situation, displaying only data essential to each phase.

4.4 The Way Forward

There are some aircraft that attempt to solve the ergonomic problems of staying head-up by bristling the throttles and the stick with switches of various kinds. This approach would appear to have reached saturation. The way forward seems to point strongly to the development and use of widespread automation of predicted tasks and to Direct Voice Input (DVI) with its counterpart, Synthetic Speech, helping to a lesser extent. These items are now considered in turn.

AUTOMATION: Over the years, Automation has crept very slowly into the cockpit. The possibility of a one-button-press selection of weapon aiming, initiating the appropriate display formats, ballistic data, ranging sensor and weapons package, has been rejected in the past because pilot options in-flight would have been reduced, making for a less flexible weapon platform. Automatic reversion from one sensor to another, however, was an accepted application for the failure case. Similarly, to allow for fast reaction over the battlefield, the automatic selection of weapon packages is now an essential feature of more modern aircraft, as is the automatic following of a flight plan.

In all these cases acceptance by aircrew depended on their being kept informed by the system of such actions and, if desired, intervention always being possible. These two caveats are of prime importance to the successful application of automation and present little difficulty with the microelectronics/microcomputing available today.

Thus, at first sight, the possibilities would seem unbounded in striving for the automatic aircraft. Such functions as Fuel Sequencing, IFF Code Change, System Reconfiguration, Communications Channel Change, are all examples for possible application. Great care must be taken, however, to understand the full implications of automating each potential candidate. For example, we must ensure that a suspect engine is not shut down on take-off or Chaff dispensed over a friendly ground radar.

DVI: For many years now, attempts have been made to design machines which respond to the spoken word, and indeed, answer back. It would appear from the wealth of literature on the subject, that much effort has been expended on total speech recognition systems with little regard for specific applications. It is probable that these specific applications, when realised, have very limited requirements particularly suited to short-vocabulary systems.

The proposed use in the cockpit is in this category. It would be quite wrong to suggest that DVI takes the cockpit over. On the contrary, simplicity of approach is essential for reliability and effectiveness. The careful introduction of DVI can have a dramatic effect on the pilot's workload in controlling the vehicle on both sides of the FEBA and in attempting to meet the requirement in the Scenario discussed earlier.

Now it has been shown in work carried out in the United Kingdom in the last decade and more recently substantiated by information at BAe Warton, that over seventy percent of the total use of voice in a two-seat aircraft is from one crew member to the other. The two brains are confirming actions and exchanging observations, activities essential to their teamwork. So the single seat aircraft clearly has an almost redundant communication channel when, at the same time, the visual and tactile channels are heavily loaded. In addition, over the battlefield the bulk of communication across the man-machine interface is one way, that is, commands into the system. Exceptions to this are warnings and the use of the HUD for the general flying task and weapon aiming.

The introduction of DVI, therefore, would seem ideal to keep the head up and to relieve the tactile channel. For example, the entry of data received when approaching the FEBA regarding a target area could be achieved by voice, saving perhaps fourteen out of seventeen actions required in using an interactive display (Fig. 6). Other applications, over the FEBA, include weapon aiming mode changes and weapon package selections, in particular the fast-reaction requirement of air-to-air modes for self-defence. It may be feasible to employ DVI in a more widespread manner in tasks specific to less hostile phases of a mission and enhance safety in the general flying task at low level.

Thus, a vocabulary of forty to sixty words would be adequate to facilitate this class of application and this fact, along with the knowledge that a continuous speech system, though desirable is not essential, should help to bound the problems faced by the research community. There are, however, other factors which need attention in the design and application of a DVI system, in particular the noisy environment, the effect of stress on the voice and the need for verification.

Greater effort goes into cockpit design nowadays to ensure the noise level is kept to a minimum and, in conjunction with the modern helmet, noise should not, in the main,

cause a problem. There will be occasions when DVI cannot be used, such as during gun-firing, but these occasions can be readily identified and accounted for in the overall moding design.

It is well known that stress can alter the characteristics of the voice, whether caused by pulling 'G' or just due to the tension of the battlefield. Breathlessness and changes in the facemask profile can contribute to distortion in the speech channel in the 'G' environment. Hence, to achieve a satisfactory level of reliability it is important that effort be directed towards the production of a voice-tolerance system.

The need to verify that the system has correctly understood and acted upon the voice input is an important psychological requirement in ensuring the pilot has confidence in the system. The method of verification may vary according to the nature of the input. A mode-change command will usually result in a change in HUD format and in combat this will suffice. The input of data, however, will require checking by displaying it, perhaps on the HUD, prior to insertion into the system. The availability of Synthetic Speech naturally lends itself well to this application and this subject is now briefly discussed.

SYNTHETIC SPEECH: The primary use of a Synthetic Speech system on the aircraft would be for warnings. Not only would such a system allow a reduction in the number of different tones for different categories of warning, each requiring rapid interpretation, but it would also be possible to tell the pilot what the problem was and recommend the action to be taken, if any. This will obviate the need, in most cases, for him to go head-down whilst diagnosing a problem signalled by an audio tone.

The points requiring attention in the application of Synthetic Speech are internal-external voice confusion, overtalking the communications system and priorities of warnings. The only way to ensure the pilot knows it is his system talking to him is to start each message with a unique audio tone and use a very distinctive voice. The problem of over-talking cannot be avoided and perhaps all that can be done in the case of a warning breaking in on a conversation is to reduce the level of the incoming speech automatically. Priorities in the warning system must be defined to cover the event of two or more warnings occurring at once. In this application the speech should be preceded by a specific warning tone to distinguish it from other messages, and accompanied by visual information on an appropriate multifunction display.

4.5 Which Drives Which?

Some of the items mentioned earlier, such as Interactive Displays, Keyboards, Data Transmission Systems and hence SCLRU's, have been influenced in some way by the rapid advances in microelectronics, in particular the abundance of processing now available to the systems designer. On the other hand, certain elements have had to be driven by the cockpit requirements, for example the improvement in CRTs. In these cases (Fig. 7) domestic/industrial requirements take the development to a plateau determined by a cost-effective limit or technological limit acceptable to that application. The military requirement then picks up the state-of-art and develops it further to a higher plateau eventually defined by new limits. This in turn may then benefit the domestic/industrial scene some time later.

The development of automation, DVI and Synthetic Speech have all been allowed by the general innovations in electronics. Automation is now in the hands of the designer. DVI and Synthetic Speech need the drive from the military requirements to turn their evolutionary processes into revolutionary ones.

5. CONCLUSIONS

This paper has attempted to define the problems experienced by the Ground Attack fighter pilot, the difficulties faced by the designer in achieving an acceptable man-machine interface in an ever-shrinking cockpit, in particular the problems of ensuring maximum head-up operation for low-level flying, and reviewed some of the facilities soon available for incorporation.

The wider use of automation and the integration of DVI and Synthetic Speech into the Avionic System is a complex task, influencing the relative use of each other as well as that of multifunction displays and controls, keyboards and more traditional switchery. It is unlikely that these new facilities will replace the old, at least until reliability has been proven. What it does mean is that the more traditional methods become reversionary methods and this fact relaxes the cockpit designer's optimisation task significantly.

The reliability of operation of the automatic elements of systems and the unambiguous transfer of information must remain prime objectives in the designer's mind. The importance of involving aircrew in system definition from an early stage must not be overlooked as the rewards in terms of crew workload alleviation will be dramatic once widespread acceptance is achieved. The first task, however, is to ensure that progress is uninhibited in making DVI and Synthetic Speech equipment available and it is here that the needs of the fighter cockpit must now drive advanced technology.

It requires the recognition of the need for the finance to be provided, the application of the scientific community to produce the solutions, the innovations of the systems designers to employ the new technology and then we can take a major step in the integration of man and machine towards greater safety and mission success.

Some years ago, one of our predecessors on the AGARD platform referred to "the aggressive exploitation of technology at its demonstrated level". These carefully chosen words point the way forward.

LIST OF ABBREVIATIONS

CRT	Cathode Ray Tube
DVI	Direct Voice Input
ECM	Electronic Countermeasures
FEBA	Forward Edge of the Battle Area
HMS	Helmet Mounted Sight
HUD	Head-Up Display
MFK	Multifunction Keyboard
SCLRU	Side-console Line Replaceable Unit

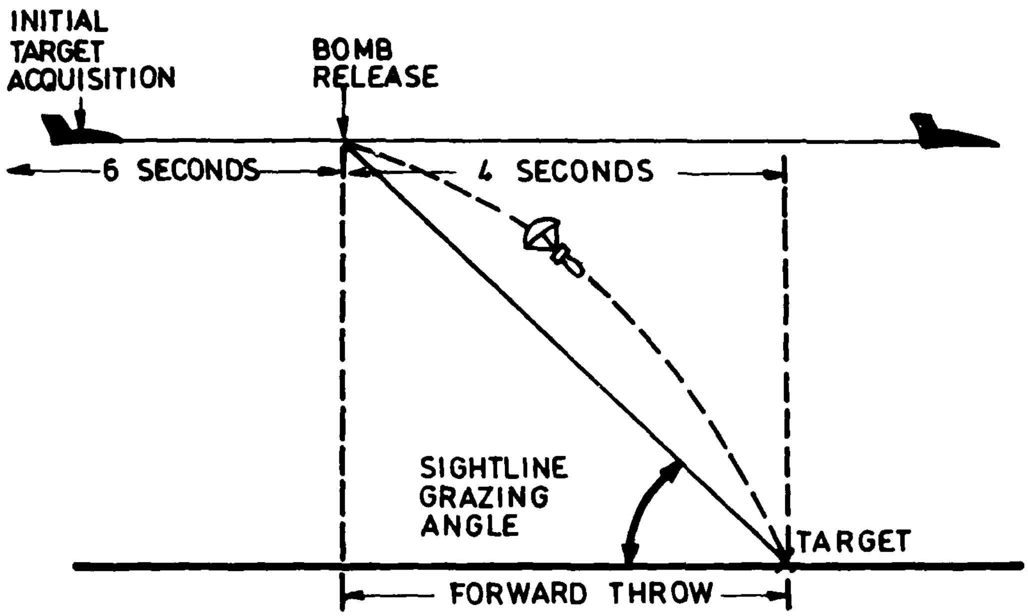
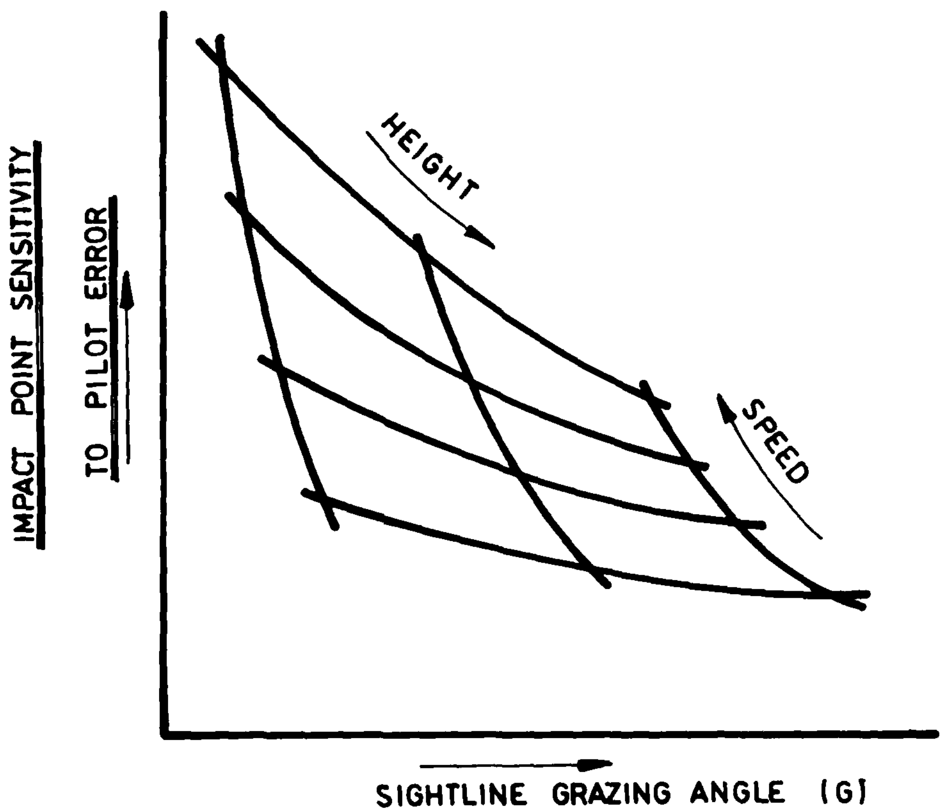


Fig.1 Retarded bombs – planned attack



$$\text{IMPACT POINT SENSITIVITY} = \frac{\text{RANGE}}{\text{SIN (G)}}$$

Fig.2 Impact point sensitivity

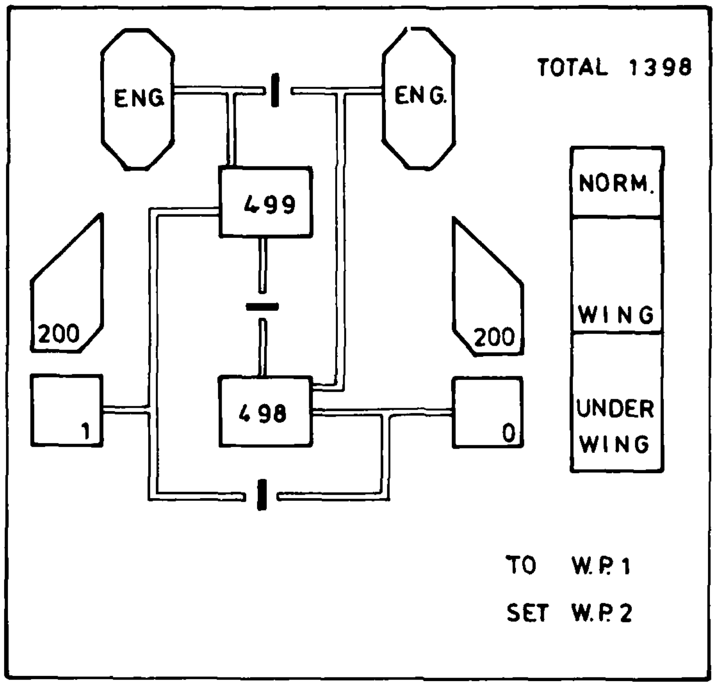


Fig.3 Touch-sensitive display – fuel system

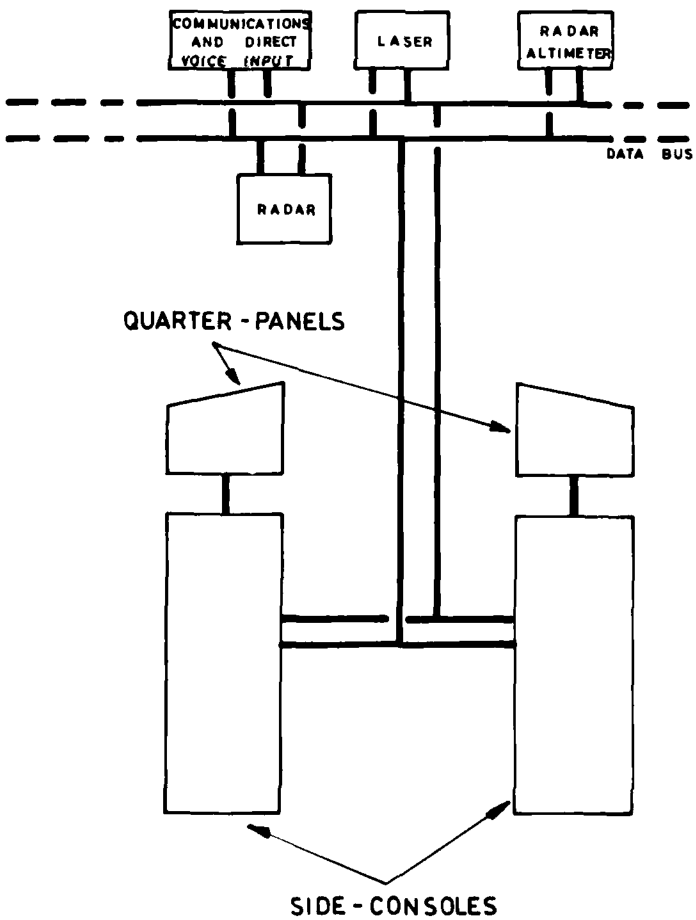


Fig.4 Side-console LRU's

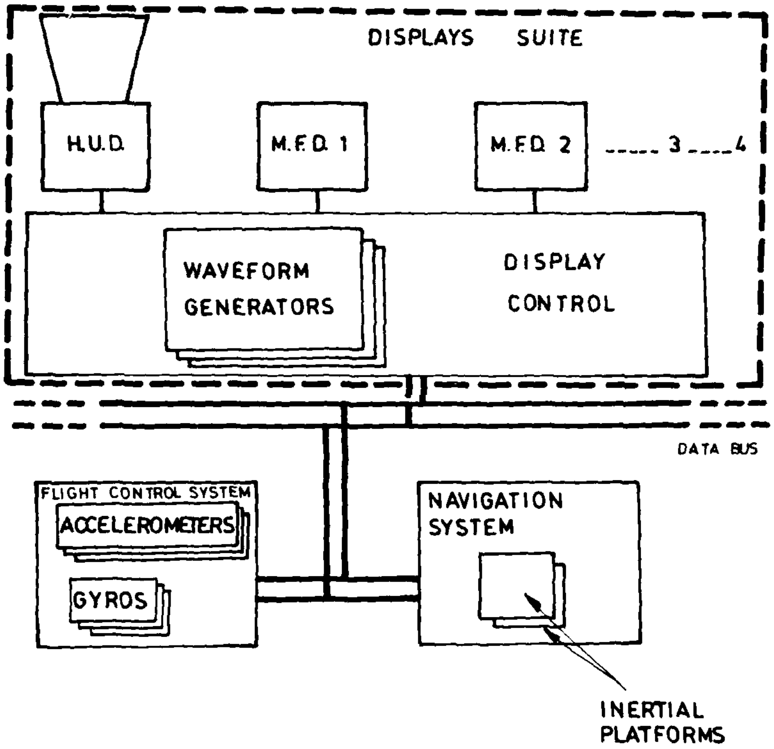


Fig.5 High integrity attitude data

DATA ENTRY OF TARGET POSITION

COMMAND	M.K.F. ACTIONS	D.V.I. WORDS	D.V.I. INSERT
TARGET 3	2	2	
INSERT	1		1
RANGE (5 DIGITS)	6	6	
INSERT	1		1
BEARING (5 DIGITS)	6	6	
INSERT	1		1
TOTALS	17	14	3

Fig.6 Direct voice input application

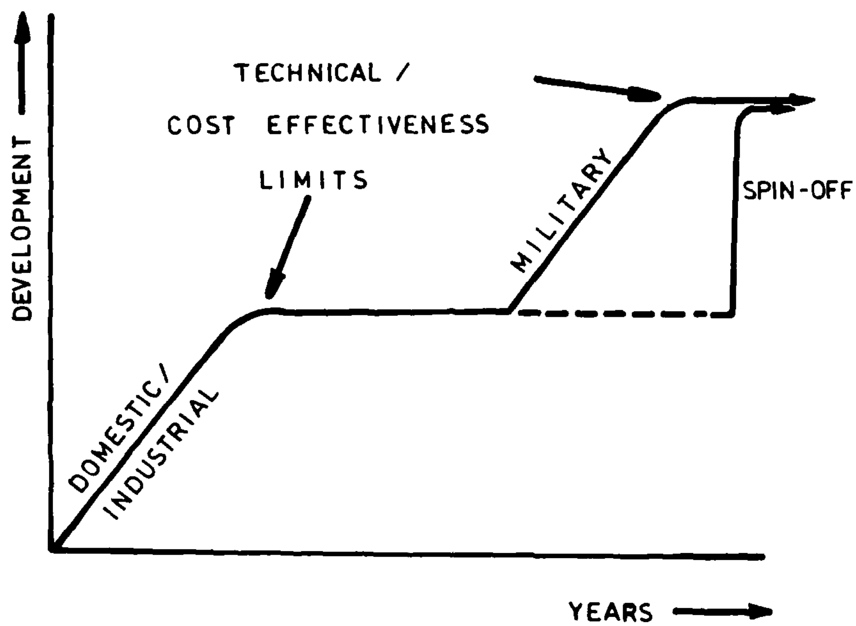


Fig.7 The development drivers

Digital Image Processing For Acquisition, Tracking, *Hand-off and Ranging*

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SUMMARY

This paper describes the design, application and preliminary analysis of flight test results of a digital processor for the automatic recognition of targets in reconnaissance images. The problems of information extraction and bandwidth reduction in raw sensor data are considered and how they lead to the evolution of a common preprocessing approach. Such features as "blobs" and edges are grouped for target classification by slope analysis. Cueing is accomplished by audible signals as well as by visual overlays on the display. Intelligent target tracking is accomplished by combining the recognition processes with conventional trackers. Scene matching for rapid handoff of target position to an associated missiles sensing system is accomplished by registration between edge ends derived from the two sensor images. Passive ranging capability for determining range to various areas of the sensor field of view is accomplished by comparing different frames of the scene using scene matching techniques. The paper concludes with a discussion of the preliminary analysis of the flight test results.

INTRODUCTION

Modern aircraft delivery systems will make increased use of FLIR imaging sensors, not only aboard the aircraft itself, but also in the weapon. These sensors will assist the pilot in getting to the target area, in acquiring targets, in determining their position, and in directing the weapons to them. The speed with which the sensor images can be processed is crucial to mission success as well as to aircraft survivability. In the case of the single-seat aircraft, demands on the pilot are so high that autonomous target acquisition, tracking, and handoff will be highly advantageous if not mandatory.

As a result of more than ten years of steady development, digital image processing systems now offer real promise for weapon delivery applications. This paper will describe the Westinghouse AUTO-Q Digital Image Processor in this role, beginning with an examination of the image processing tasks involved in target acquisition, tracking, and handoff. The basic concepts and algorithms in AUTO-Q will then be described, as well as the evolution of three generations of digital hardware. A description of the electrical and mechanical characteristics of the latest system will be provided, and finally the results of the flight test program conducted in May 1981 will be presented.

IMAGE PROCESSING OPERATIONS IN WEAPON DELIVERY

In the weapon delivery scenario, the image processing operations of target acquisition, tracking and handoff can be further detailed in the following manner.

Target acquisition is initiated by a search of the sensor over the region where targets may be found. It is desired to acquire targets at the maximum possible range. This leads to the use of a narrow field of view moving rapidly over the search area, with resulting high data bandwidth. The search requirement largely determines the minimum allowable bandwidth for the image processor, and it is an attractive area for the use of compression techniques such as analysis.

A successful search will result in the detection of targets. Detection probabilities will be improved for targets which occur in clusters if this possibility is taken into account. Classification of detected objects is necessary to separate the targets of interest. These may then be prioritized in accordance with the mission demands. Unless the system is fully autonomous, the resulting target information must be provided to the human operator by visual or audible cues.

In preparation for weapon delivery, priority targets must be tracked at field or frame rates. If they are moving relative to their background, accuracies of one or two pixels are required by conventional correlation trackers so as to avoid confusion with background clutter. Such trackers have difficulty with partial obscuration of the target, or with temporary disappearance combined with a change of course. One approach to improved tracker performance under adverse conditions is to combine the speed and accuracy of the correlation tracker with the target acquisition capability of the image processor.

If the weapon contains a separate imaging sensor, positional information regarding targets must be transferred to it from the image processor. Since very little target detail may be available in the weapon sensor, it is attractive to perform the handoff operation using scene-matching algorithms. It is desireable to provide an algorithm which can operate between sensors which differ in scale, resolution, and even spectral characteristics.

The autonomous handoff problem places several demands on the scene matching algorithm. [illegible] of survivability and successful attack, target transfer should be accomplished within a fraction of a second. For tracking purposes a precision of less than one pixel (TV line) is required. [illegible] of the boresight alignment characteristics of the two sensors, handoff must be accomplished [illegible] initial misregistration of the two sensor fields of view is as much as half of the [illegible] field of view. Handoff has been demonstrated in the laboratory using the AUTO-Q [illegible] with a special software package.

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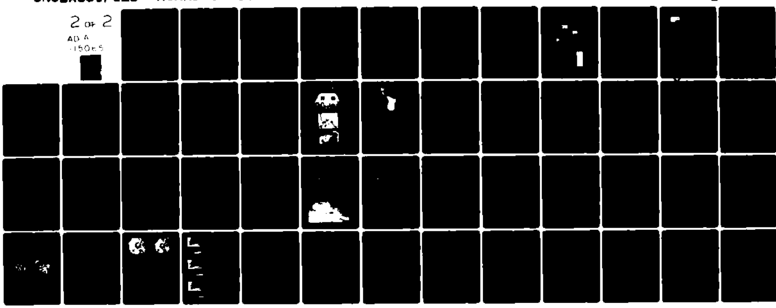

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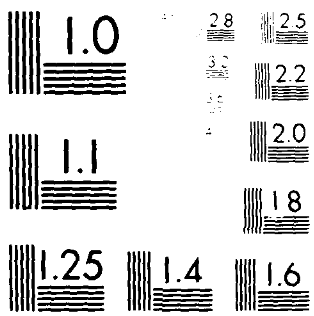

MICROCOPY RESOLUTION TEST CHART

EVOLUTION OF AUTO-Q HARDWARE

The AUTO-Q development follows an earlier program for the development and test of a laboratory breadboard cueing. system. The breadboard was used for the processing of videotaped imagery at rates of 1-2 frames per second. However, processing was limited to a 100 x 100 pixel window in the field of view. The location and class of detected targets was shown on an array of LED characters located on the periphery of the display, which proved difficult to follow in rapidly changing scenes. The system was rackmouted and was unsuitable for installation aboard attack helicopters.

The steps in the evolution of the AUTO-Q system are shown by Figure 1. The construction of the first breadboard followed the development of the basic digital image processing algorithms in 1968, and their testing by computer simulation on FLIR targets from 1970 to 1973. Tests with the breadboard revealed a number of problem areas which were corrected by the development of an Advanced Laboratory Breadboard under Westinghouse sponsorship. Major areas of improvement were:

1. Digital storage of image data;
2. Window size increased to 128 x 128 pixels;
3. Revised image preprocessor with improved performance and greatly reduced size, weight, and required power;
4. Symbol generation mixed with image video, and under software control.

As a result of experience gained with the Advanced Laboratory Breadboard, two separate third generation hardware developments have occurred. The first is the development of the AUTO-Q system which is the subject of this paper. The second was the construction of an operational Westinghouse AUTO-MATCH System for NASA-Goddard. The AUTO-MATCH system performs image correlation or scene-matching, and uses the same image processor hardware as AUTO-Q system.

The hardware commonality between AUTO-Q and AUTO-MATCH makes possible the development of an AUTO-Q system with expanded capability, but with essentially no increase in size or complexity. By time sharing the AUTO-Q functions with AUTO-MATCH, a capability for passive ranging to the target can be added, so as to assist in the target screening process. The AUTO-MATCH function can also be used for handoff of target coordinates from one sensor to another. Expansion of AUTO-Q capabilities can also be achieved by adding a correlation tracker, in such a way that the cuer and tracker are coordinated in an "intelligent" manner. In this way, the cuer can initiate the target track, and can re-establish tracking if loss of lock occurs for any reason.

WHAT IS AUTOMATIC CUEING?

We define "automatic cueing" as the use of automatic recognition devices to initiate appropriate audible or visual signals or cues to assist the human interpreter in his evalution of sensor images. The cueing system acts as an information filter on the sensor data, selecting images of importance mixing them with visual indications of target location, and providing audible alarms to attract the attention of the interpreter. First; the image is digitized for use by the image processor. Preprocessing of the digitized data serves to reduce its bandwidth by retaining only the information necessary for automatic recognition. When recognition of desired targets has been accomplished, appropriate audible and visual cues are initiated. These cues will not only indentify the target types, within the limitations of sensor resolution, but can also provide precise coordinates of their location in the image. A variety of target types can be accommodated simultaneously by the cueing system.

THE NEED FOR AUTOMATIC CUEING

The need for automatic cueing arises from the limitations of the human observer in examining displays. Two such limitations are:

1. The speed of the eye in performing search operations, estimated to be equivalent to a bandwidth of approximately 100 kHz (Gardiner, F. J. 1971). In rapidly changing TV formats with considerable detail or clutter, the eye can adequately examine only a small portion of the image;

2. The "boredom factor," which refers to the loss of performance in search operations experienced by an observer when the time between target occurrences is extended. As the probability for an immediate detection decreases, his concentration decreases.

Data available on human performance in target acquisition appear to support the above statements. Under laboratory conditions, acquisition of less than half of available targets can be expected when clutter is present (Jeffrey, T. E. 1968, Evans, S. H. 1971). Under field conditions, the situation appears much worse (Masster, 1971).

PROCESSING OPERATIONS IN AUTO-Q SYSTEM

Digitizing of video image

Frame Buffering

Image Preprocessing

Group Forming

Classification

Frame Integration and Prioritization

Symbol Generation and Display

These functions are shown in the block diagram of Figure 2 with a description following.

The output of an imaging sensor, as provided for visual displays, usually consists of a uniform two-dimensional array of intesnity values (pixels). Useful information, such as the outline geometry of objects of interest, must be extracted by computations involving both pixel intensity and position. When these computations have been performed, there is the prospect that the desired information can be expressed at a greatly reduced bandwidth (one or two orders of magnitude) from the original image data. For the AUTO-Q function, this bandwidth reduction is extremely important, since it is desired to rapidly detect and classify targets which are very small in relation to the sensor field of view, and which may be located anywhere within it.

The sensor input is directed to a buffer which stores a single frame at the videc rate. Following synchronization and digitizing of the incoming video signal (either 525 or 875 line formats), the stored data is provided to the preprocessor on a line-by-line basis at a slower rate.

The configuration and adjustment of the preprocessor is under software control on a frame to frame basis. A variety of pixel conditioning options are offered, including averaging filters, a median filter, level slicing, and rate compression. Level slicing at two levels is provided so that simultaneous isolation of both light and dark regions may be accomplished. Rate compression reduces the flow of image data by selection of alternate pixels.

Pixel conditioning is followed by gradient extraction to obtain both amplitude and directions for a two-by-two pixel array (Roberts Cross). When this operation is preceded by averaging filters, the equivalent of operators with more smoothing but lower resolution (such as the Sobel operator) is obtained. The gradient operation is a first derivative computation on the image data. All gradient values above an adaptively selected amplitude threshold are outputted to the blob tracker, and to the maximize function.

The blob tracker detects conditions which indicate the top of a potential blob. Left and right outlines are then tracked through the image on a line-by-line basis. The length of the vertical path is retained, as well as the extent of the left and right excursions. The blob is detected when a matching left and right outline connect.

Maximize is a second derivative operation which thins the gradient data into the fine lines of the target, including both the outlines and the internal detail. It compares neighboring gradient values in both the x and y directions. In the process,edge sharpness and amplitude are also derived.

The segment tracker moves down the image on - line-by-line basis, defining the endpoints and polarity of image edges. This will occur for edges associated with targets as well as for background definition of roads, trees, etc.

The group forming function gathers the straight-line segments associated with successful completions of the encircled target area blob tracker. This is accomplished by forming a table for each of the potential group numbers. Each table contains all of the addresses in the output buffer memory for the line segments with the same group number. This eliminates searching the entire buffer memory for line segments associated with targets. This permits the syntactical classification algorithms in the processor to directly collect all the component descriptors of the targets. Output from the group formation logic is provided to the general-purpose processor mini-computer which is an integral part of the AUTO-Q hardware. Outputs include groups which represent potential targets, and edges associated with background.

Final recognition of target classes will be carried out in the mini-computer as well as frame integration and prioritization. The AUTO-Q system must be provided with the reference information necessary to discriminate desired target classes. This information is obtained from a reference data base, consisting of samples of the various target classes taken under representative conditions. The collection of blobs and edges associated with a potential target is used to generate a set of measurements or features, and these are compared to reference features for the target classes of interest using a decision tree.

The preprocessor outputs are sorted in Group Formation and presented to the mini-computer as individual packages of information associated with potential targets. It is the function of the classifier to take a group of edges and blobs associated with a single potential target, to extract feature measurements from the group and to compare them with reference features for each of the targets of interest. The selection of features , and their values for the target classes may be obtained from representative image samples. Decision logic is then generated which places each incoming object into one of the target (or non-target) categories. Feature computation and decision making

is contained in the mini-computer software package of the AUTO-Q system.

Frame integration involves the comparison of a sequence of images to improve the classification results for a particular target. Prioritization involves the ranking of several targets in the order of their importance. Both functions are carried out in software.

Once a target is located and classified, its position will be marked on the display, and an appropriate symbol will be used to define the target class. The choice and location of symbology is under software control. In our present laboratory demonstrations, targets are enclosed in a rectangle, and a single letter of the alphabet is placed nearby to define the target class. The problems to be avoided are the obscuration of the target by the symbols, and the interference between symbols in the target groups.

An example of the preprocessor operation on a FLIR image of a jeep is shown by Figure 3. The 50-by-50 pixel image is shown at top left, and the numerical array of intensities is shown at top center. Of the 16 available intensity levels, values above nine are indicated by an over-printed slash (/). Gradient directions are also quantitized to 16 directions with a 1 indicating a change from light to dark to the right. Where the gradient amplitude (not shown) is less than a predetermined threshold, no output is shown, and the location is marked with a dot. The result of gradient maximizing (line-thinning) is indicated at the left, where some of the previous gradient outputs have been deleted if they are adjacent to a similar output of larger amplitude, and if their presence in edge formation is unnecessary. Edges are formed by tracking the thinned gradient output, and by recording both the beginning and endpoints of each track. They are shown on the graphical plot at the bottom of Figure 2. The window at right indicated the accumulated angles associated with tracking around a blob. The resulting blob symbol, a cross, is shown on the graphical plot, along with the edges. The height and width of the blob is indicated by the length of the arms of the cross.

AUTO-Q SPECIFICATIONS

Input:	Standard Interlaced; 60 fields/sec.
	525 lines/frame or 875 lines/frame.
Sample Rate:	525 line: 11.333 MHz
	875 line: 17.000 MHz
Pixels/Line:	512 for either 525 or 875 lines
Resultant Nominal Coverage -	
525 line:	86 percent of active width
875 line:	2.8 percent blanking overlap
Lines/Frame - 525 Interlaced:	480; pixel aspect ratio: 1.08
525 Single Field:	240; pixel aspect ratio: 0.54
875 Single Field:	420; pixel aspect ratio: 1.06
Pre Sample Filter	3 db cutoff frequencies
for 11.333 MHz Sample rate:	4.2 MHz
for 17.0 MHz Sample rate:	6.0 MHz
Minimum attenuation at	
sample rate:	36 db
Output Data Rate:	at clock rate provided by preprocessor
Memory growth to interlaced	875 line with 64k memories
Output Dynamic Range:	36 db (6 bits)

PHYSICAL CHARACTERISTICS

The AUTO-Q processor is housed in a lightweight chassis measuring 19.35 cm (7.62 inches) by 25.7 cm (10.12 inches) by 49.69 cm (19.56 inches). The structure is a standard chassis design and construction techniques that were developed for and are presently in use on the F-16 radar computer. The design will accommodate 24 electronic assemblies, 21 switchwired or printed wiring boards, two SEM-16 type planar memory modules, and a power supply. The rear wall of the chassis will provide an opening and fasteners for a 10.1 cm (4-inch) tube axial fan. All of the electronic assemblies are easily removable from the chassis. The front panel, which contains all of the electrical connectors and the elapsed time indicator, is removable from the chassis and the interconnecting matrix plate which in turn electrically connects to all the electronic assemblies. The weight of the processor is 22.68 kg (50 pounds).

INCREASED CAPABILITIES

Consideration of the mission scenarios for automatic cueing has revealed several functions which are complementary to the recognition capability and which are expected to be in demand for future systems applications. Because of the versatility of the AUTO-Q image processing techniques, it will be possible to perform these functions with limited hardware and software modifications. They are considered as growth items to the initial cuer capability. The following additions are described below:

1. Passive Ranging;
2. Autonomous Handoff;
3. "Intelligent" Tracking.

PASSIVE RANGING CAPABILITY

Target recognition test with the AUTO-Q system have demonstrated improved performance, particularly in the rejection of false alarms, if range information is available. When the sensor is pointed toward the horizon, for example, an entire clearing may appear bloblike, and possible be confused in shape with a tactical target if range is unknown. With range information available, such potential false alarms can be rejected on the basis of size.

A passive ranging capability can determine range to a specific target location using the existing AUTO-Q hardware, but operating in the image registration or AUTO-MATCH mode. In this mode, two successive looks at the target are compared as the aircraft moves, and their geometric differences are used to calculate range. The AUTO-Q image processor contains all the hardware required to perform AUTO-MATCH (registration) operations. In order to perform these operations, approximately 4,000 words of processor memory are required.

The time required for computation is estimated to be 0.3 second, but this will depend on the stability of the sensor gimbals. If the gimbals are highly stable, the acquisition problem could be simplified, and this figure could be reduced.

Inputs required to the AUTO-Q system for passive ranging are the aircraft position change between looks, and the relation of this vector to the line of sight of the sensor.

It now appears that this passive ranging approach could yield accuracies to better than 5 percent, and that further improvement could be achieved by repeated looks at the target. Such accuracies are quite sufficient for improved false alarm rejection.

AUTONOMOUS HAND-OFF CAPABILITY

Since the automatic target cueing process results in the precise determination of target position in the sensor field of view, it is potentially useful to transfer this information directly to another aircraft, or to a missile. Under the assumption that an imaging sensor is present aboard the second vehicle, the hand-off operation may be accomplished by a correlation operation between the images in the first and second vehicles. The correlation process registers the scene in the first vehicle in which the target has been recognized and located, to the scene in the second vehicle, which is assumed to contain the target. The correlation process compares the overall scene; therfore, it is possible to register the two scenes even if the target cannot be resolved in the second sensor. This is important if the second vehicle sits at a longer range from the target, or if it contains a low resolution sensor (a missile, for example). Correlation between sensors of different wavelengths and different resolutions has been demonstrated. Techniques for automatic cueing are similar to those for registration or correlation, and they make use of common hardware. The same preprocessor is used for both operations. Therefore, with relatively minor modification the AUTO-Q system could be programmed to perform image correlation for hand-off operations. Operation in the screening or hand-off modes could be alternated on a frame-to-frame basis, if desired. The operation is similar to passive ranging, except that the image from the second sensor replaces the second look for passive ranging. The AUTO-Q preprocessor would be used for both images.

INTELLIGENT TRACKING CAPABILITIES

Successful weapon delivery requires a coordinated interchange between target acquisition, high-speed track, and hand-off to the weapon system. Once the cuer has located and classified a target, these operations can readily be set in motion. "Intelligent" tracking or the coordination of cuer and tracker functions, is described in this paragraph.

The concept of the "Intelligent Tracker" was probably originated as a result of development of automatic target cueing. Cueing systems inherently possess the following advantages which conventional trackers lack:

a. Autonomous detection and recognition of targets over the entire snesor field of view.

b. Re-acquisition capability if tracking is interrupted.

c. Handling of many targets simultaneously, with prioritization to select targets of prime interest.

d. In the selection of critical aimpoints, knowledge of target classification greatly simplifies the problem.

Cuers are, in fact, powerful tracking systems. However, because they are designed to contend with the high data rates associated with full-frame operation, they generally operate at frame rates of 3 to 10 frames per second. For positioning of gimbal or servo systems, 30 frames or 60 fields per second may be necessary. For precision determination of track points, within a target, the target detail employed by a correlation tracker may be necessary. Therefore, the combination of the cuer and tracker as an "Intelligent Tracker" appears to offer potential performance well beyond current capability.

In addition to the above, a feature which should be offered by the Intelligent Tracker is "signature prediction." Present day target trackers and terminal guidance homing systems encounter severe degradations in performance when operated in environments with high clutter backgrounds. As the target moves to a new background region, these trackers and homers wait until the correlation outputs diminish, and then they attempt to reaquire the target under difficult conditions. What is needed is the ability to identify the approach of a *conflicting background situation*, and to modify the processing to take it into account.

A block diagram of an "Intelligent Tracker" modification to the AUTO-Q system is shown by Figure 4. The entire system could be contained within the Engineering Model chassis, contained within the dashed outline. Interfacing systems are the sensor, guidance equipment, display, and operator controls. Within the chassis are contained the AUTO-Q hardwired processing equipment, the software operations, and the tracker insertion. Each area is delineated by dashed lines on this figure.

The processing operations carried out by the conventional AUTO-Q system are shown at the left. However, output from the analog-to-digital converter (at the sensor data rate) is supplied to the tracker subsystem for operations at the sensor frame or field rate.

When the AUTO-Q system has located targets of interest, tracking may be initiated automatically on the target of highest priority. Secondary targets are tracked in addition, but at the slower rate of the cuer.

Tracking would be initiated by position information provided to the tracker select and store area, which extracts a reference image (16 by 16 pixels) from the 32-by 32-bit binary buffer. Input to the buffer is obtained at the frame or field rate from the binarizer. The threshold for the binarizer is updated continuously by a histogramming operation on the binarized data surrounding the target.

Following storage of the binary tracker reference, new frames are correlated with it as they arrive, and the position data are forwarded to the guidance system via the "Quality Monitor." The Quality Monitor also receives from the tracker a measure of the quality of the correlation output, i.e., signal-to-background ratio. If this value is reduced below a preset threshold, a positional update on the target is requested from AUTO-Q.

An additional input to the Quality Monitor is the offset data required to achieve a specific traget aimpoint, as specified by AUTO-Q.

Signature prediction is carried out by joint operations between the AUTO-Q software and the tracker. A proximity search is made of the AUTO-Q output to identify the presence of objects or clutter in the path of the tracked target, which will interfere with tracking. The motion of the target has been estimated by two or more sequential examinations of the target prior to classification. Objects or clutter may take the form of other vehi les, trees or bushes, grass or road are, etc. If no specific object is found in the target path, then a window will be located in the path at a location sufficiently far in advance that no influence from the target will be encountered. (For small targets, this is usually one target width.) A second binarizer will be used to determine the distribution of gray levels which will be encountered. This information will be transmitted to the threshold selector used with the tracker so that a new threshold can be set which minimizes the effect of the interferring clutter.

AUTO-Q FLIGHT TEST

During May of 1981, the AUTO-Q system was installed aboard a Hughes OH-6 observation helicopter equipped with a Forward Looking Infared (FLIR) sensor. Targets were situated in an open field approximately one half kilometer wide by three kilometers long. Roads had been constructed in the field for the maneuverability of the target vehicles. The targets were tanks, armored personal carriers, flat bed trucks, and jeeps. Approaches to the target area were at an altitude of 500 feet or less, with cueing system operation beginning at eight kilometers and terminating at two kilometers. The weather conditions were varied with bright sunshine, overcasts, and raining days.

The results of the flight test were promising and were similar to the results obtained under laboratory conditions. The data was broken into two range categories; two and a half kilometers to five kilometers and two and a half kilometers to eight kilometers. The overall averages were as follows:

Range/Kilometers	%Targets Detected	%Correct Recognition
2.5 to 5	65.4	38.0
2.5 to 8	53.8	33.4

The quality of the imagery was categorized into four levels and analyzed under the same range conditions as before. The following table is the results of that analysis.

Range 2.5 Kilometers to 5 Kilometers

Image Quality	% Targets Detected	%Correct Recognition
Minimal	24.2	59.2
Poor	59.8	36.7
Fair	78.5	32.4
Good	76.2	39.1

Range 2.5 Kilometers to 8 Kilometers

Image Quality	% Targets Detected	% Correct Recognition
Minimal	14.6	59.5
Poor	46.4	32.7
Fair	69.1	24.1
Good	63.0	34.6

As was ecpected as the quality of the imagery improves so does the detection rate, but there is little if any effect on the percentage of correct recognition.

CONCLUSIONS

Following years of painstaking preparation, digital image processors are now approaching their moment of truth in gaining acceptance as an integral part of the process of target acquisition and weapon delivery. Although some setbacks are possible, they are expected to survive this test. Further performance improvement is expected as a continuing evolution.

It is also believed that the design of the AUTO-Q system represents a major step toward the development of a production cueing system. Packaging is in a military format. The volume of less than one cubic foot will be useful for certain applications without modification. Reduction in volume by as much as 30 percent could be achieved by elimination of certain processor functions which were included primarily for the evaluation tests. The resulting package would then be shortened by the elimination of some circuit boards.

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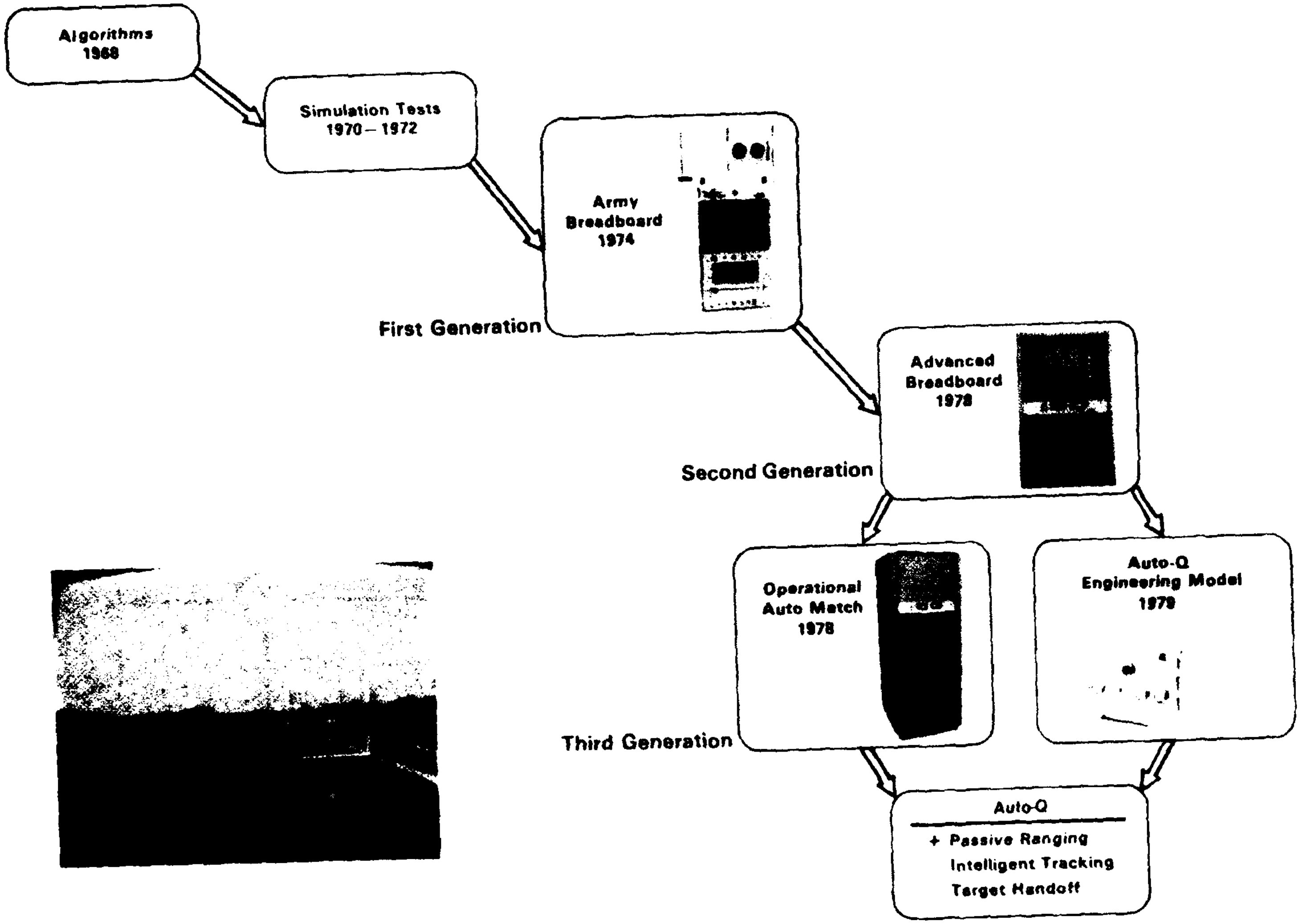

Figure 1 - Evolution of AUTO-Q System

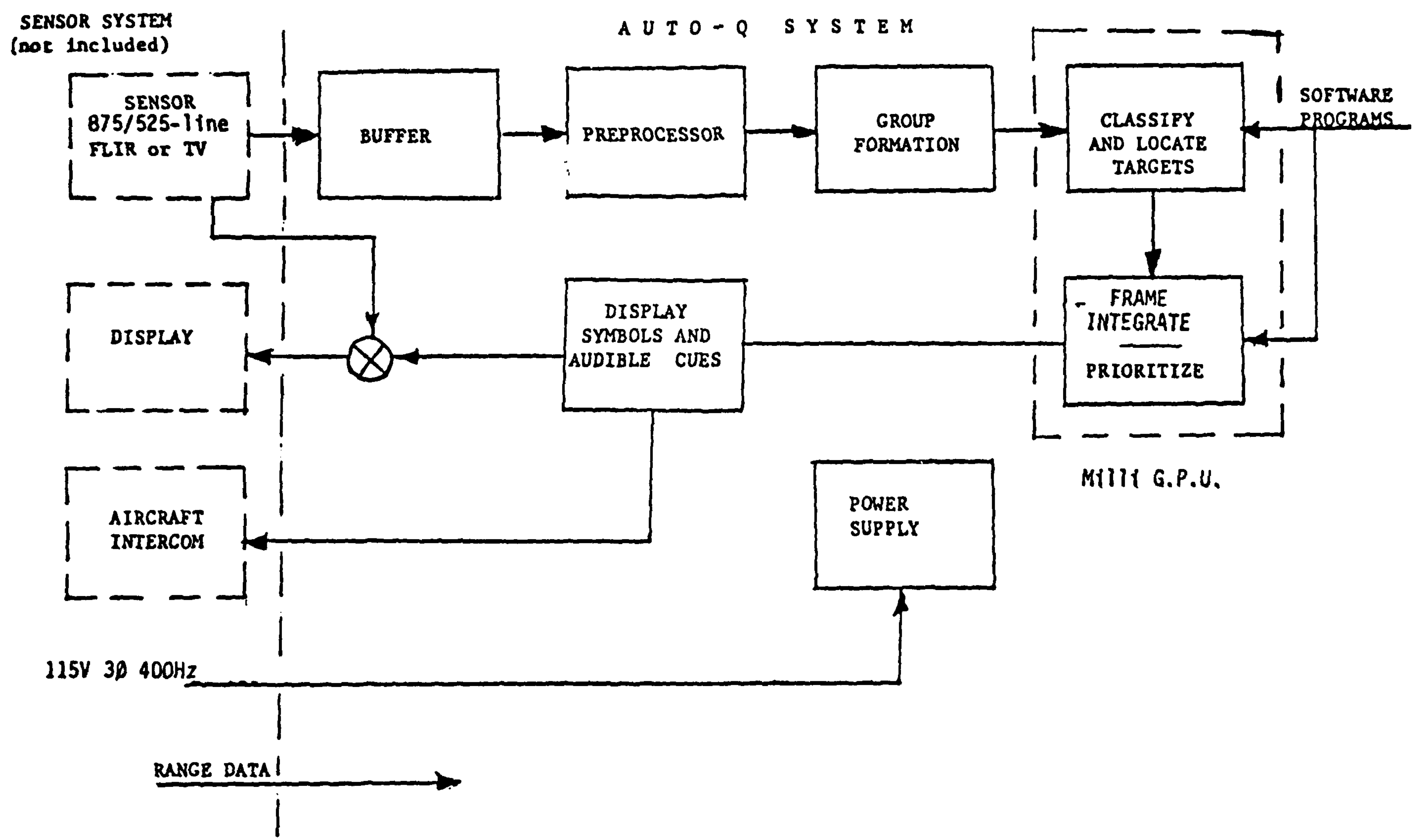

Figure 2 - *AUTO-Q Block Diagram*

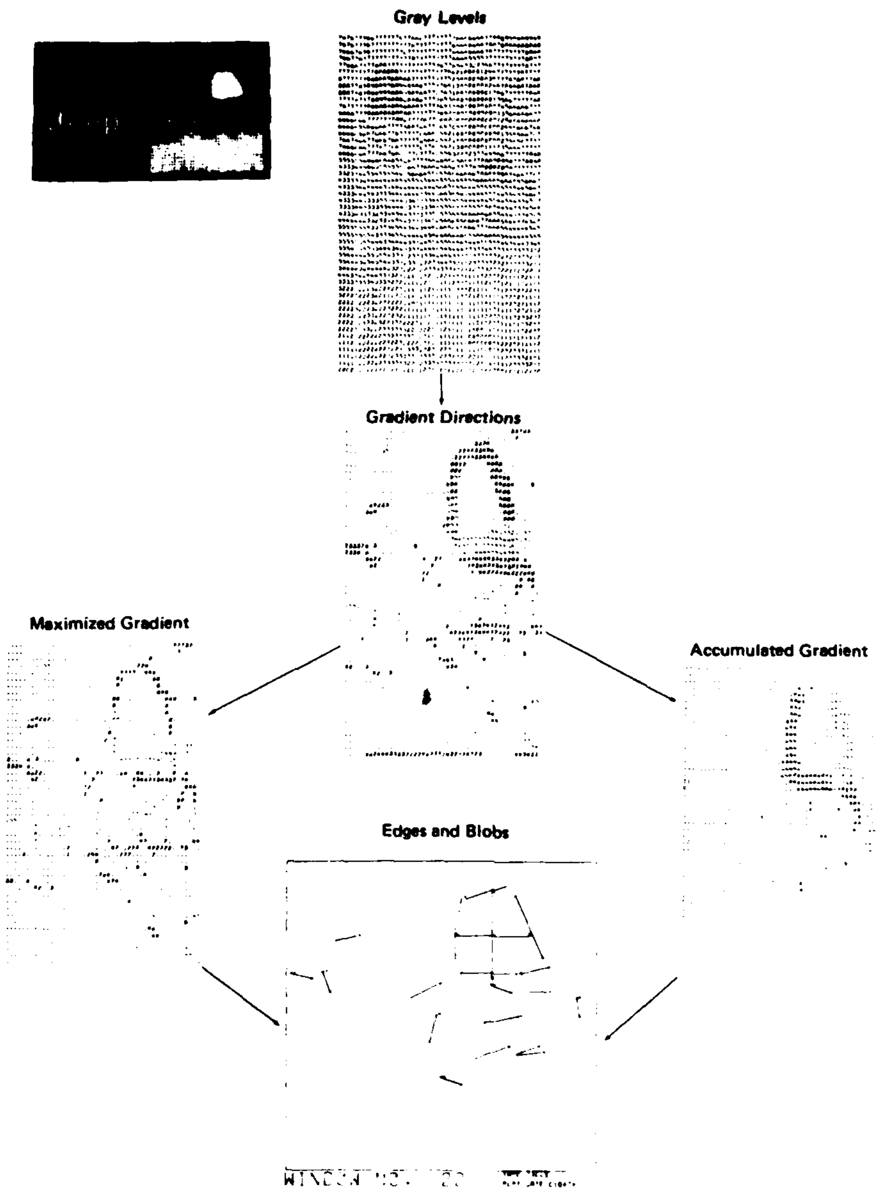

Figure 3 - Example of Preprocessor Operations

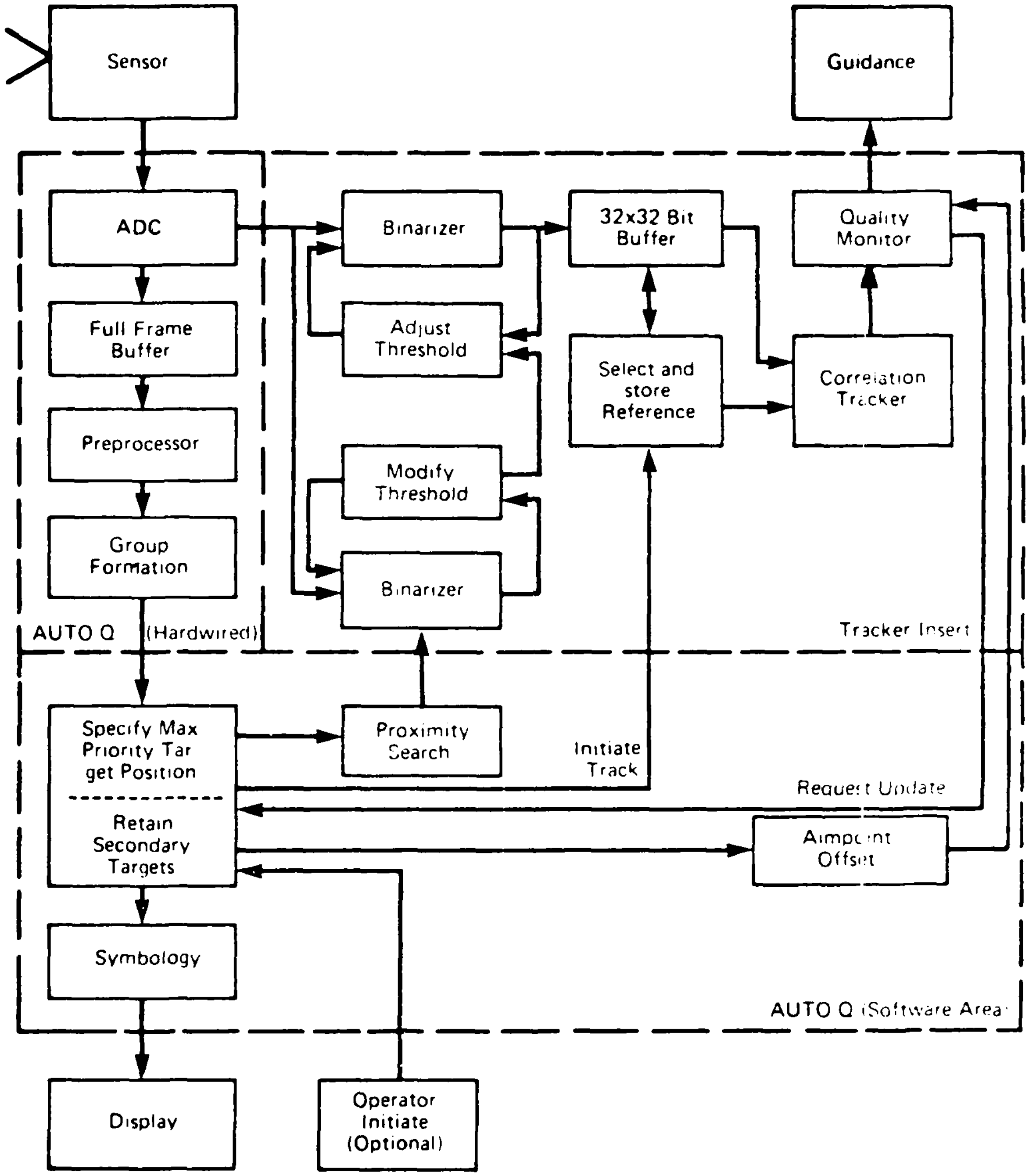

Figure 4 - Intelligent Tracker Modification to AUTO-Q System

WIDE ANGLE RASTER HEAD UP DISPLAY DESIGN AND APPLICATION TO FUTURE SINGLE SEAT FIGHTERS

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SUMMARY

Requirements to fly low and fast at night and in adverse weather have lead to techniques to provide the pilot with a synthetic forward view of the real world. Simulation and flight trials in the UK and USA have confirmed the need for a wide field of view (FoV) imaging sensor for this purpose driving a Head Up Display (HUD) with a corresponding FOV.

The pilot uses the display to fly as he would in daylight, effectively visually, using familiar cues to judge speed and terrain clearances, to navigate and identify targets. A large lateral(FoV)is necessary to allow detection of off track waypoints and targets, while a significant FoV in elevation is required to allow the pilot to see into turns and to support aggressive manoeuvering. However, while operational needs suggest a large FoV, sensor resolution and mechanical cockpit constraints provide practical physical limits.

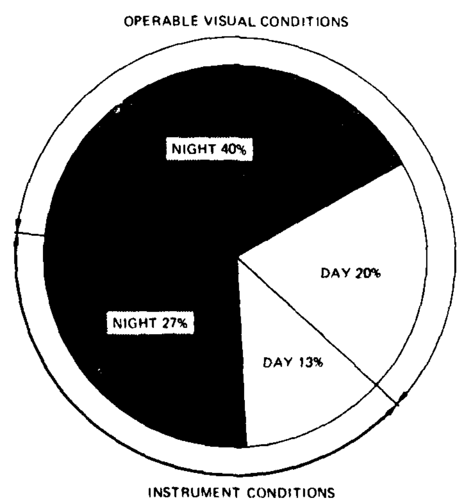
This paper describes unconventional optical designs capable of the largest practical FoV, around 20 degrees by 30 degrees for the majority of existing fighter cockpits. Some ancillary advantages implicit in the designs are also outlined. HUDs of this type are currently in development for the USAF LANTIRN programme and will be flown in the F-16 and A-10. They are also compatible with a wide range of other fighter aircraft.

1. INTRODUCTION

The paramount need, to overcome heavy enemy armour and to strike at command, control, and logistic centres, will ensure that survival in the face of increasingly sophisticated air defences will dominate fighter tactics and require the provision of a wide variety of self defensive aids. Defence destruction, confusion, and stealth techniques all have their parts to play in this.

The stealth tactic of flying low and fast can be effective in countering all but the most sophisticated air and surface defences and would be further enhanced, because of reduced defence effectiveness, if such missions could also be accomplished with reasonable safety at night and under the weather. Indeed, it is under just such conditions that an aggressor could be expected to advance or bring up reinforcements, planning to use highways with relative impunity. In a central European winter, the most favourable period for such conditions when visual flying is often restricted to 20 percent of the day, the bulk of Allied single seat day fighters will generally be grounded. Low level interdiction and strike would then be the responsibility of a relatively few expensive two seat fighters. Their effectiveness will depend almost totally on the use of mapping and terrain following radars and their operations would principally be limited to high value targets or area weapons.

Marked benefits occur if significant quantities of relatively inexpensive day fighters are adapted to extend their low level operations to the night or under the weather. There is evidence to suggest that such a capability would extend their operational usefulness during this critical winter period from about 5 hours to 16 hours a day, see figure 1. A careful mix of day/night/all weather capabilities would then balance cost and performance, reserving the more expensive and sophisticated aircraft (F-111, Tornado, F-15E etc.) for the more extreme weather and mission conditions.



1. Central Europe in Winter

This powerful force multiplier is achieved by providing the single seat day fighter pilot with pseudo visual conditions, projecting a synthetic forward view derived from an imaging sensor (LLTV or FLIR) in a one to one relationship with the real world. By making the image large enough, the benefits of perspective and peripheral vision can be derived to give the pilot the sensations of VMC flight, enabling him to use familiar visual cues to judge speed and terrain clearances, to navigate and to identify targets. On its own, this additional facility provides a striking and cost-effective extension to the capability of most fighters. It also offers the attractions of covert (passive) operation when this is necessary. However, performance can be further enhanced by automatic aids to ease the pilot's workload during these very demanding missions. Some of these aids might permit automonous multiple target recognition, designation and attack, allowing the single seat pilot to concentrate on navigation and survival. In the case of these latter tasks, it is reasonable to expect the pilot of the late eighties to be aided by significantly more automation than at present, in addition to the primary night sensor/HUD visual aid.

The popular argument about the choice of either single or two crew to carry out such complex missions is irrelevant in this context: the concept involves extending the performance of the present large fleets of day fighters, not necessarily to an ultimate capability, but rather to a different limit, bounded by pilot performance and reasonable hardware costs. Needless to say however, what is cost effective in improving single seat fighter performance is likely to provide a similar benefit for two crew configurations.

Existing conventional refractive HUDs (USN A-7E) have been used to project FLIR night vision scenes into the pilot's forward view, but with magnified, sometimes gimballed, sensor images, they are unable to give the pilot the necessary synthetic wide forward view of the real world on which he depends for confident safe high speed low level flight at night. The dangers of attempting such missions while manual terrain following with a small FoV HUD has been likened to "driving on the highway with a peep-hole cleared on the windshield" ref. 1. Flight tests have confirmed the need for a large FoV imaging sensor scene projected to infinity with a one to one correspondence with the real world. The tests have shown that a minimum instantaneous FoV, i.e. that part of the total scene visible from one head position, of 15 degrees by 20 degrees is necessary but that a larger instantaneous FoV (IFoV) is essential to support more aggressive manoeuvering or improved off track waypoint/target detection. The largest practicable FoV is the critical parameter governing the pilot's ability to fly safely at low level and this requirement has governed the design of a new generation of HUDs using novel optical techniques. Figure 2 illustrates the striking improvement achieved in an actual F-16 installation, achieved without impact to the existing instrument panel, canopy, etc.

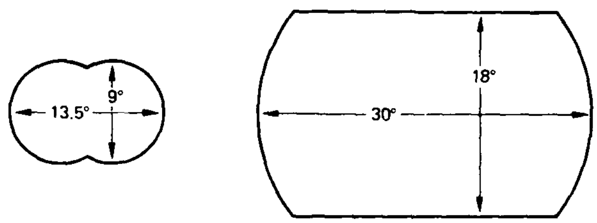


Figure 2. Instantaneous Field of View Improvement

The sensor scene, received by the HUD as a standard television video signal, is projected with the necessary one to one angular correspondence with the real world. Textural, perspective, and peripheral cues are available to the pilot to judge speed and terrain clearances. The greatest practicable "up" vision is provided to allow him to see into turns while a very large lateral view enables him to detect off track targets. The synthetic scene is overlayed with the normal daytime symbology to provide the pilot with VMC equivalent conditions. Indeed, experience has indicated that pilots usually elect to reduce symbol brightness against the scene background, flying on normal visual cues with occasional scan checks of symbolic HUD flight data, just as they would fly head up at low level in daytime. Indications are that these FoVs are compatible with reasonable sensor resolution and range, although this aspect is not considered further in this paper. Smaller FoVs result in higher or slower flight and consequently, reduced survivability.

An essential requirement of this new Wide Angle Raster HUD (WARHUD) is that, in daytime use, it should not exhibit degraded performance in comparison with more conventional HUDs. Indeed, it offers considerable improvement: the large FoV, essential for the low level night mission, is also attractive in other roles; the greater efficiency of the optical system allows the CRT to be derated giving increased brightness and longer life; the human factors aspects, allowing full automatic brightness control during high workload low level flight, are of benefit in other regimes, contributing to overall flight safety. Other specification parameters are at least maintained.

2. DESIGN FOR LARGE FoV

Although FoV is not the only novel aspect of the WARHUD, it is the single most critical parameter driving the design. The final design choice has not been selected in an arbitrary manner but only after a thorough review of a very wide range of contending optical geometries. It is worth noting here that a conventional refractive HUD design, see figure 3, has its IFoV limited by two critical dimensions, the size of the collimating exit optic which, when reflected by the combiner, provides a virtual image of the display superimposed on the pilots forward view of the real world, and the distance of this image from him. The angle subtended gives the IFoV, increased laterally by binocular vision and sometimes vertically by multiple combiner glasses. Increasing the FoV can be achieved by enlarging the "porthole" or by bringing closer: the first tends to impact instrument panel space while the latter rapidly infringes normal safe pilot ejection criteria. Some improvement in FoV is generally possible by such means, but not nearly enough to provide the really significant increases required for the low level night mission.

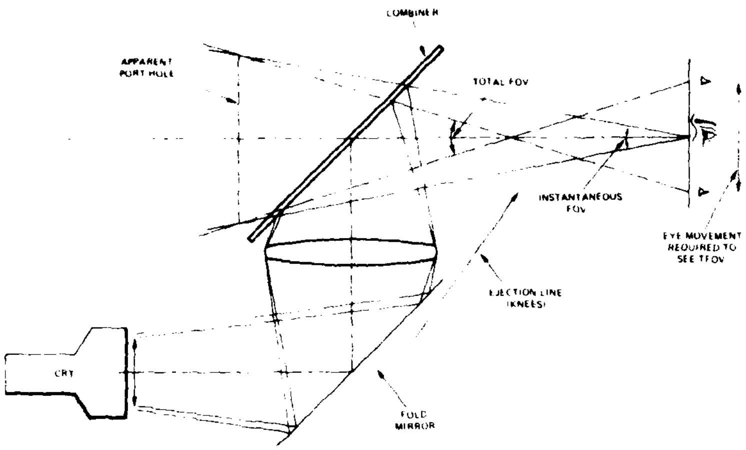


Figure 3. Conventional Refractive HUD

Other techniques are necessary, but the foregoing description is of assistance in understanding the logic of the new approach. It will be apparent that the most advantageous HUD IFoV will be achieved if the collimating element is above the instrument panel where its size is limited only by canopy clearance, and if it is as close to the pilot as possible, as shown in figure 4. This particular arrangement has a number of positive attractions: the large spherical collimating surface provides the largest practicable IFoV; the radius of curvature is large allowing it to be sandwiched between two planar elements to provide an undistorted view of the real world: the relatively small angle of incidence and long focal length dramatically reduce the aberrations that are present in more off-axis systems. As we shall see later, these minimal distortions allow significant simplifications in the design and manufacturing process.

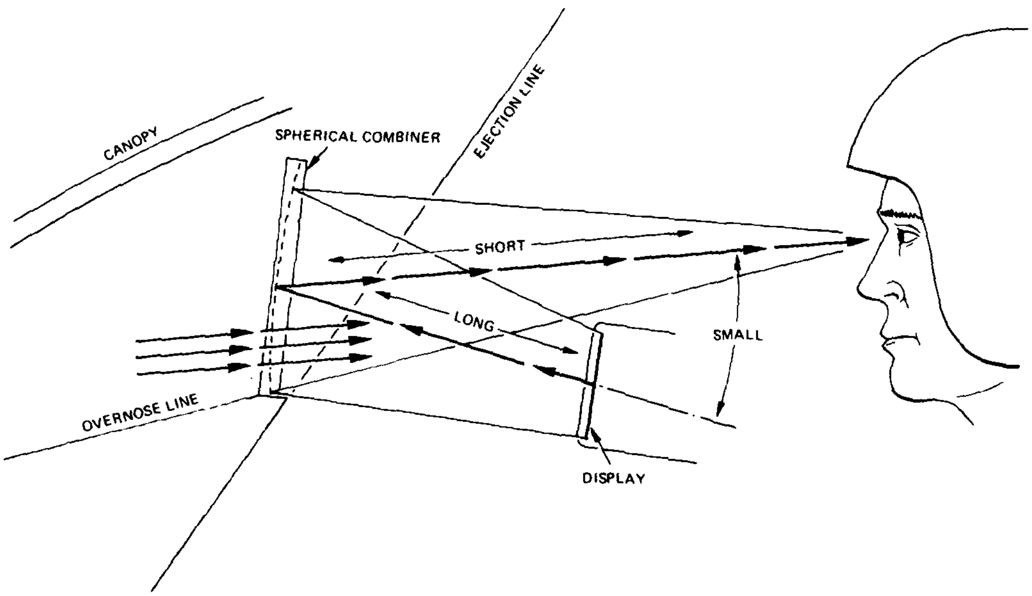


Figure 4. Ideal Combiner Position

Of course, the image is in quite the wrong place and so some plane mirrors are required to fold the optical path and allow the CRT and a relay lens system to be buried in the conventional location, behind the instrument panel, see figure 5. Obviously, all glass elements above the glare shield must be transparent to allow the pilot an uninterrupted view of the real world. They must also sometimes be transparent to CRT light and sometimes reflect it strongly to allow the HUD image to reach him.

This apparent paradox is resolved by the use of highly angularly selective optical coatings which will only reflect a narrow band of wavelengths incident at a particular critical angle. Although the optical geometry would work in theory with multilayer reflection coatings or even neutral density ones, optical efficiency would be so degraded that the HUD would be unusable. The only coatings offering sufficient selectivity are diffraction surface created by a photographic technique more usually used to make holograms. The coatings are designed to act on the very narrow band of wavelengths emitted by the CRT phosphor (P43) and in practice approach 100 percent efficiency as individual reflectors. However, because of the number of surfaces involved and because of the inevitable slight mismatches between phosphor bandwidth and coating reflection characteristics and other losses, the light of the CRT actually seen by the pilot is reduced considerably. Indeed some deliberate detuning is sometimes necessary to ensure that the pilot may continue to view the display while moving his head away from the design eye position. But the remaining efficiency still exceeds that for a conventional HUD optical system where

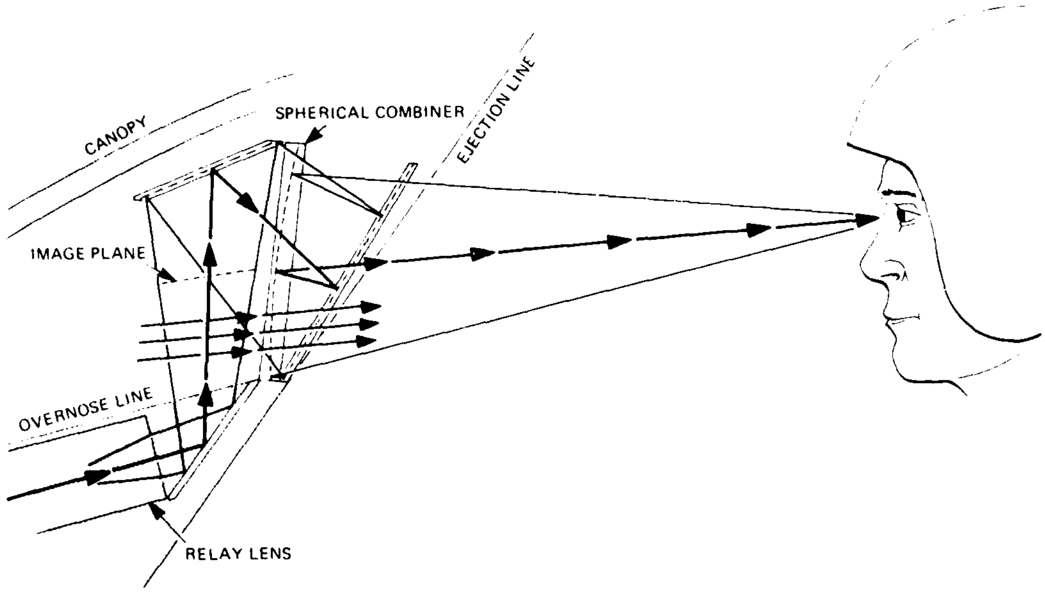


Figure 5. WARHUD Ideal Optics

most of the light is transmitted straight through the combiner glass and is lost. The diffraction coatings act equally on light from the real world in that they select from it the same narrow band of green wavelengths and reflect them away. The effect of this subtraction of green is to make the real world seem to the pilot to have a slight pinkish tinge. One of the principal reasons that the coating is designed to be so selective is to ensure that this discolouration is kept to a barely noticeable minimum.

Some of the optical configurations that were evaluated in detail are shown in figure 6. On the left is a class of diffraction optics we have designated "off-axis". It represents one of the earliest attempts to apply the technology in the most direct way but it suffers from a number of penalties. The curvature of the combiner in such a system provides the principal collimating function but is too great to allow the use of a planar doublet to sandwich the diffraction coating. The necessary protection is provided by two pieces of curved glass which reduce the thickness of the element and thus its weight to an acceptable level. The curved combiner not only introduces certain practical manufacturing problems but also contributes to the apparent distortion of the real world seen through it. However, the two major drawbacks are more immediately apparent: the lower mirror tends to intrude into the ejection clearance path, restricting how close the combiner may be brought to the pilot and hence limits the FoV available; a further restriction in elevation is contributed by the windshield clearance, reducing the further forward the combiner is located; and the large off axis angle causes very large optical aberrations.

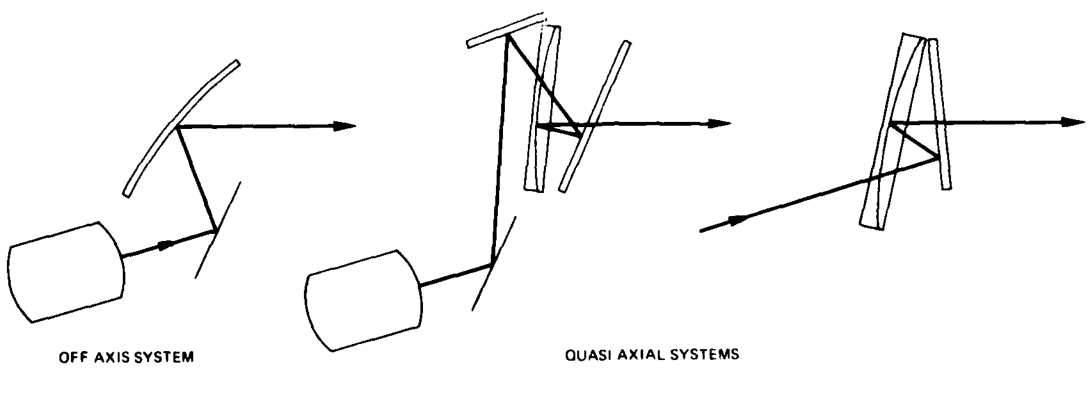


Figure 6. Alternative Optical Designs

It is impossible to reduce the off-axis angle in this configuration since to do so would shift the combiner even further from the pilot. The intrinsic aberrations must be corrected by introducing compensating aberrations in the hologram itself and in a complex relay lens. Such a design still has problems since it is only practicable to correct an inherently highly aberrated system for one eye position, the view from a different eye position will remain highly aberrated.

By comparison with the off-axis systems, the other class, termed quasi-axial, have a much reduced critical angle of incidence for reflection. Aberrations are minimal and do not require compensating aberrations in the diffraction coating itself; the limited corrections necessary can be implemented in a simple relay lens. Indeed, in the case of the system on the right of figure 6, no relay lens at all is

provided and the residual errors in the unaberrated design, although slightly larger than desirable for a high accuracy HUD, are acceptable for certain applications. Such "lensless" designs have been built and evaluated.

The central figure 6 system of course represents the WARHUD design which is the subject of this paper. It does not suffer from the sun reflecting off the rear surface which can create a problem with the "lensless" design, and it embodies the principal advantages of the quasi-axial design class. The diffraction surfaces do not require "power" allowing them to be made easily, while residual aberrations are compensated in a simple relay lens. The cross section of the body of the HUD mounted behind the instrument panel is small in both height and width, simplifying installation in a wide variety of cockpits. Full advantage of this economy in the use of prime panel real estate can be taken in new cockpit designs, allowing the instrument immediately beneath the HUD to be located much higher than might otherwise be possible.

Before describing how the quasi-axial design simplifies manufacture, it is worth considering how the holographic technique is used to create the diffraction surface. A thin film of photosensitive dichromated gelatin is exposed to two beams of coherent laser light. Due to the coherent nature of the incident beams a series of interference fringes are formed throughout the depth of the gelatin film. During the developing process these fringes are converted to planes of high and low refractive index parallel to the film surface. To a first approximation the refractive index change between adjacent planes is sinusoidal. During the developing process, the gelatin swells producing an increase in the tuned wavelength. Retuning the hologram is achieved by baking the film which reduces the thickness and hence the spacing between planes of constant refractive index. The designer therefore specifies a construction wavelength corresponding to the desired reflection wavelength at a given angle of incidence after baking. The bandwidth of the angular reflection range is determined by the magnitude of the change in refractive index. This variable can be controlled during the developing process and is specified as the hologram modulation. Of course the critical angle of reflection varies over the hologram surface and the required diffraction characteristics are largely determined by such factors as the pilot's eye position and head motion, the field of view required and the geometry. An interactive iterative design process using a suite of CAD programs is used to optimise the optical system design and to meet any particular installation constraints. The construction points of the three holographic surfaces can then be determined, care being taken to ensure that the overall photometric characteristics are satisfactory.

The lack of power (or aberrations) in the diffraction elements allows a greatly simplified manufacturing technique to be used. Figure 7a shows the normal method used to create the two interfering beams

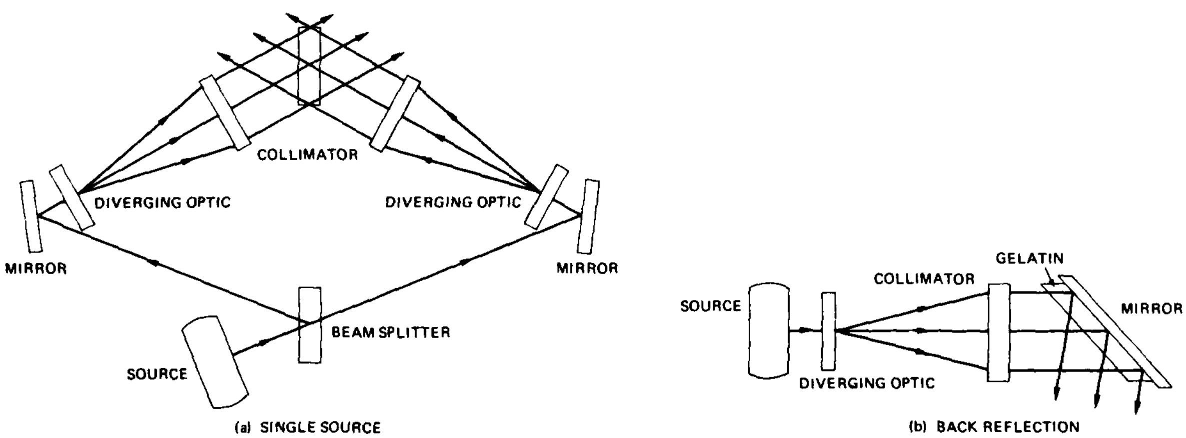


Figure 7. Diffraction Element Exposure

using a beam splitter. Such a technique is necessary in order to introduce the aspherical optical elements into the path of the laser light to create deliberate aberrations. However, path lengths are necessarily long, creating exceptional stability requirements of fractions of a wavelength over a period of exposure lasting several minutes. The aberrating elements themselves can also create problems, tending to cause unwanted secondary holograms to be recorded in the gelatin. The unaberrated quasi-axial design permits a simple back reflection hologram construction technique to be used as shown in figure 7b. Fringes are created by the interference of incident and reflected rays. As a result, the separated path length can be measured in microns and stability and exposure time requirements can be reduced to the level where they no longer create manufacturing yield problems.

The quasi-axial WARHUD thus provides the largest practicable IFoV without impact to the cockpit installation, provides transmission and reflection characteristics superior to conventional HUDs, and allows straightforward hologram manufacturing techniques to be used. Interestingly enough, in addition its other virtues and almost as a side effect, it rejects the bulk of sunlight reflections which can cause problems with other HUD designs, both refractive and diffractive.

3. OTHER CONSIDERATIONS

The HUD optics, key though it is, is only a part of the equipment. The image generating CRT requires deflection, video amplifiers, power supplies, synchronization and raster scan generating circuits, phosphor protection and built in test and, usually, a separate digitally controlled Symbol Generator Unit to drive

it. But the list does not end there: a number of other functions are required which need to be treated differently in the WARHUD than in a more conventional display.

The raster requirement for the night scene demands that a different approach be adopted than the usual daytime slow speed high brightness cursive scan. Two basic alternatives are possible, bearing in mind that the CRT has one gun and can carry out only one display task at a time. Either the daytime symbology must be converted to a synchronized raster video and mixed electronically with the sensor video prior to display or the complete night symbology must be written at high speed in the only available time, the vertical retrace period of the raster. In the event, the latter approach has been preferred because of the overall economy of having a single symbol generation technique, albeit one with a night mode writing requirement some eleven times faster than the day mode, and because of the consistency in the high quality of the symbology achieved by this means. Special features are included to reduce the power dissipation normally implied by a high bandwidth deflection amplifier design.

A frequent HUD requirement is to provide a collimated depressible standby sight, available in the event the electronic system fails, and totally independent of it, although the case for such a sight is reduced as improved technology extends equipment reliability. The most successful method of injecting the standby reticle into the optical path has been used on a very large number of conventional HUDs, A-7D/E, A-4M, F-16, etc. A red reticle image is injected via a dichroic beam splitter. It is particularly efficient because it reflects most of the red light without significant attenuation of the green CRT light. With a diffraction HUD that only operates at a very narrow band of green wavelengths a different approach is necessary. The obvious technique using a neutral density beam splitter and a green standby reticle is inefficient because it would cause significant attenuation of both light sources. As a result, and rather than compromise the main display for the sake of a standby facility, WARHUD can be provided with an electronically generated standby sight using a microprocessor in the Display Unit. Its operation is completely independent of the separate main Symbol Generator Unit but of course it does depend on the continued functioning of a large part of the display, fortunately, a relatively high reliability item.

To relieve the pilot of the manual tasks associated with display brightness and contrast control, particularly when he is flying low at night, beneath cloud or in bright moonlight, an advanced auto-brilliance control is provided, sharing the same microprocessor as the standby sight. Where current day HUDs provide automatic control over 3 decades of ambient scene brightness, the WARHUD control extends this through a further 2 decades, down to a 1 foot lambert night scene. Clearly it would be quite unreasonable to expect a pilot already trying to cope with multiple complex tasks to also be concerned with anything quite so mundane but nevertheless potentially disturbing. Such considerations are applied throughout the design to ease pilot workload at all times.

The HUD camera recorder presents problem with any diffraction HUD. Because of the limited range of positions from which the display can be seen, the recorder can not be mounted in the conventional position, looking through the combiner glass. To see the display satisfactorily, it really needs to be co-located with the pilot's head. The only really viable alternative is to provide a scan converted version of the display symbology, achieved relatively efficiently using currently available digital technology. The synchronised raster video output is then mixed electronically with either a CTVS camera video, now mounted forward of the combiner, in the day mode, or the sensor video at night. The mixed video is passed to an airborne VTR with all the attendant benefits of this now widely preferred recording method.

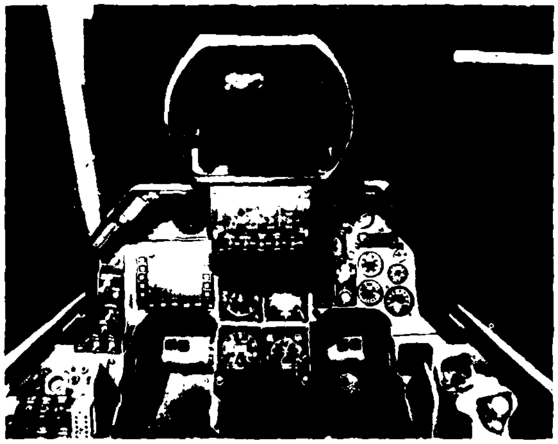
Another interesting implication of the WARHUD design is that it allows the normally closely clustered HUD symbols to be distributed over the larger FoV, reducing display clutter. However, such potential should be treated with caution. HUD symbols are scanned in the same way as conventional head down instruments: a wider distribution could tend to increase scanning time and hence pilot workload.

4. ADAPTABILITY

The first application of WARHUD is in the F-16 as part of the USAF Low Altitude Navigation and Targeting Infra-red for Night (LANTIRN) System. Since a development contract award in July 1980, the design is now far advanced, see figure 8 showing a model of the WARHUD installed in the present F-16 cockpit where it will begin flight test in the summer of 1982 and in the more advanced F-16 MSIP 2 cockpit planned to enter production in 1984. The FSD prototype HUD is approaching first delivery in January 1982.

The WARHUD design has proved most adaptable. Two cockpits could not be more different than the F-16 and the A-10, but the same basic design has been applied to each. Although the A-10 optics are 30 percent larger in order to subtend the same FoV at the more distant eye position, some 80 percent of subassemblies are common between the two equipments. The A-10 program is proceeding equally successfully and according to plan, some months behind the F-16. Installation studies carried out to date have shown that the F-16 HUD is straightforwardly compatible with a number of aircraft types including: A-7, Tornado, Viggen, F-15, F-18, Jaguar, and Harrier. Indeed, there would be plenty of room to spare if the conventional HUDs in most of these aircraft were replaced with the high performance WARHUD.

(a) Wide Angle Head Up Display



(b) F-16 Development Installation

(c) F-16 MSIP 2 Production Installation

Figure 8. WARHUD Installations

(d) A-10 LANTIRN HUD

Figure 8. WARHUD Installation

5. CONCLUSION

The WARHUD, when coupled with a suitable night vision sensor offers many operational advantages. However, the ability to upgrade large existing fleets of single seat fighters with a covert night capability for a relatively limited cost is most striking. Development, now well advanced, offers a zero risk design which exhibits none of the drawbacks of earlier diffraction HUD configurations.

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7. ACKNOWLEDGEMENTS

The discussion on diffraction optic design owes much to the work of the optical design team in the Marconi Avionics, Flight Automation Research Laboratories. Their work has lead to the CAD software library allowing diffraction HUD design to be optimised with speed and confidence. My thanks to General Dynamics for the cockpit photographs.

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ADVANCED TARGET ACQUISITION AND TRACKING CONCEPTS FOR REAL-TIME APPLICATIONS

by

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SUMMARY

The basic functional requirements for the target acquisition mission based on the sensor input, preprocessing, image segmentation, feature extraction, target detection and target classification operations are presented. The impact on designing real-time tracking algorithms to follow targets through clutter is considered utilizing today's technology. An advanced tracking concept considering the coupling of the target detection/classification algorithm with the multi-mode track is discussed. The thrust for multi-sensor systems is considered from the synergistic target acquisition point of view. The implementation of smart sensor target acquisition functions are presently hardware throughput limited. The advancement in the very high speed dedicated integrated circuit technology will make present advanced algorithms realizable in new integrated circuit hardware. The projected needs for real-time target acquisition and tracking are considered for the autonomous vehicle. Several approaches are considered for realization of the truely real-time target acquisition system in the next decade.

1. INTRODUCTION

The target acquisition process, employing electro-optical image processing techniques, utilizes smart sensor algorithms to detect and recognize the potential targets in a search field. This process is applicable to both "man-in-the-loop" and autonomous functions.

The objectives of the generic smart sensor concept include the improvement of military exchange ratios implying that the inclusion of a smart sensor function in a fire control system will increase its survivability and result in a higher kill potential against a specific foe. A second objective is to provide longer acquisition-standoff ranges. This is particularly relevant to "task limited, man-in-the-loop" applications where the smart sensor function automatically cues the operator to a particular target for ranges at which he could not otherwise faithfully search. Another objective is to reduce the reaction time in search to increase the system survivability. This is important in scenarios where the system becomes vulnerable due to long exposure times. Therefore, by performing the search process with the smart sensor at a rate exceeding the operator's performance rate, the system life expectancy is significantly improved. A fourth objective is ultimately to take the "man-in-the-loop" out of the loop and perform the task autonomously. However, before this objective is realized many correlaries will be established to supplement present day fire control operators with task simplification functions; such as global and local gain-brightness functions, target cueing operations, and target tracking.

The technological challenges brought to bear in realizing the above objectives dwell on the general "motherhood" issues. Size, weight, and power become a dominant consideration in implementing the functions desired in the smart sensor. Many of the general operations exist in large main frame computers. However, even these giant number crunching systems cannot perform the algorithms in reasonable image sizes in near real-time. The ability to instrument the algorithms in today's specialized hardware presses the real question as to the maintainability and producability of the hardware in a military environment. Further confrontations such as life cycle costs make the ultimate smart sensor payoff a significant challenge to realize. The level of intelligence for each application which can be traded off for ultimate costs is yet to be determined.

If the technological issues can be overcome, the smart sensor concepts have many systems payoffs. Certainly, one of the most obvious areas is the remotely piloted vehicle (RPV). This can be a small unmanned aircraft with a very limited payload which can perform search, target acquisition, and relay the information back to a remote station through secure, narrow band communication links. Ultimately the target acquisition function along with target prioritization, multiple target tracking, and bandwidth compression functions must be performed on the vehicle to allow the information to be communicated in such a narrow band data link. The applications extend to such areas as attack aircraft where search time is an important aspect of survivability, the autonomous fire and forget missile and smart projectile arenas where size, weight, and level of intelligence must be traded off for maximum payoff, and possibly land combat vehicles which include the multiple target tracking and prioritization functions.

The implication of real-time operation in the performance of smart sensor algorithms is not trivial. As a general example, let us consider a conventional 525 TV raster which utilizes a four by three aspect ratio with a 80% scan efficiency per frame. This gives rise to approximately 225 thousand picture elements (pixels) in the single frame. All of these pixels will be read out in a single frame as low as one thirtieth of a second, leading to an analog pixel rate of greater than five mega-pixels per second. If we assume the signal amplitude of each pixel can range over 60 decibels (1000/1), the conversion to the digital domain will require about ten digital bits per pixel. This results in a digital bit rate of greater than 50 mega bits per second. The algorithms considered in the front end of the target acquisition function involve data manipulation and modification which presses the state-of-the-art in through-put capabilities of today's hardware.

The objective of this paper is to summarize the general target acquisition functions and propose some advanced concepts in both semi-autonomous and autonomous scenarios which are performed in real-time. Section 2 establishes the subsets of the target acquisition operation including target prioritization. In Section 3, the basic target tracking concepts are reviewed, with the needs for intelligent target tracking brought out. In Section 4 the synergistic multi-sensor target acquisition operation is presented. The projected needs and general tasks for the real-time target acquisition scenarios are discussed in Sections 5 and 6 respectively. Conclusions are presented in Section 7.

2. THE TARGET ACQUISITION OPERATION

There are several target acquisition algorithms presently instrumented in state-of-the-art hardware. Each approach utilizes a different concept in performing the target detection function. However for the purpose of this discussion let us use the block diagram shown in Figure (2-1) to summarize the autonomous target acquisition operation.

The sensor-input depends on the types of sensors employed, their readout configuration, and analog to digital conversion techniques. Target acquisition algorithms may vary depending on the sensor. Both contrast and brightness features vary with the imagery developed either by day-time television, medium-wave-infrared (MWIR) sensors, long-wave-infrared sensors (LWIR), or others. The detector readout format varies with the IR system. Present day mechanically scanned FLIR systems utilize electro-optical scan conversion techniques to convert the parallel scanned image into a TV compatible serial output. The advancement of integrated focal plane technology is significantly increasing pixel densities with time and also expanding throughput requirements of A/D converters. This increases the input bit rate to the target acquisition operation. A second case in point is that staring focal planes in the LWIR may have to operate at high frame rates to prevent signal saturation in the FPA signal processor (Ref 3).

The preprocessing function is that very important operation where the digital signal is conditioned in preparation for the target extraction operations. A global gain-brightness operation may be employed by averaging the background over a large portion of the image, sensing the maximum-minimum signal levels, and expanding the gain from black-level to saturation. A pseudo-DC restore function may be employed to correct for signal droop in A/C coupled systems. A more recent image conditioning function, the local area gain-brightness compensation, in which the signal in a region where the contrast is very low is amplified in the local region to increase low contrast targets and backgrounds has been instrumented in real-time hardware. The second generation focal plane FLIR requires real-time non-uniformity correction circuitry for both DC offsets and responsivity variations for every pixel. All of the pre-processing functions must be performed at the pixel level in real-time.

The segmentation process results in a segmented image in the form of image blobs. Such operations as median filtering to reduce high frequency image noise and edge operators are initially applied to the preprocessed pixels. The extracted edge maps are then thinned. Thresholds are adaptively established for both edges and brightness. Connected component techniques establish the perimeter of the blobs. The segmented blobs are separated into features which lead to the target detection process. The feature space is made up of several geometric characteristics such as blob area, perimeter, width-to-length ratio, and perimeter-to-area ratio. Also the number of edges and edge straightness are considered along with the average bright-ness and contrast of the blob.

The next operation optimizes the discrimination factors initiated in the feature extraction, rejects the clutter, and detects the basic targets. Through the feature match process, targets of interest can be separated from a cluttered environment. The moments of the targets are calculated to aid in the classification process. The K-nearest neighbor classifier has been used to perform the classification function. Here the term classification means the detected targets have been classified into categories denoting the type of target; such as a tank, armored personnel carrier, truck, etc. (Ref 4). The basic approach is summarized in Figure (2-2). After the classification is performed, it is important to prioritize the targets according to the greatest threat. This is done by the feature match process again with built in priorization rules dependent on the classified targets.

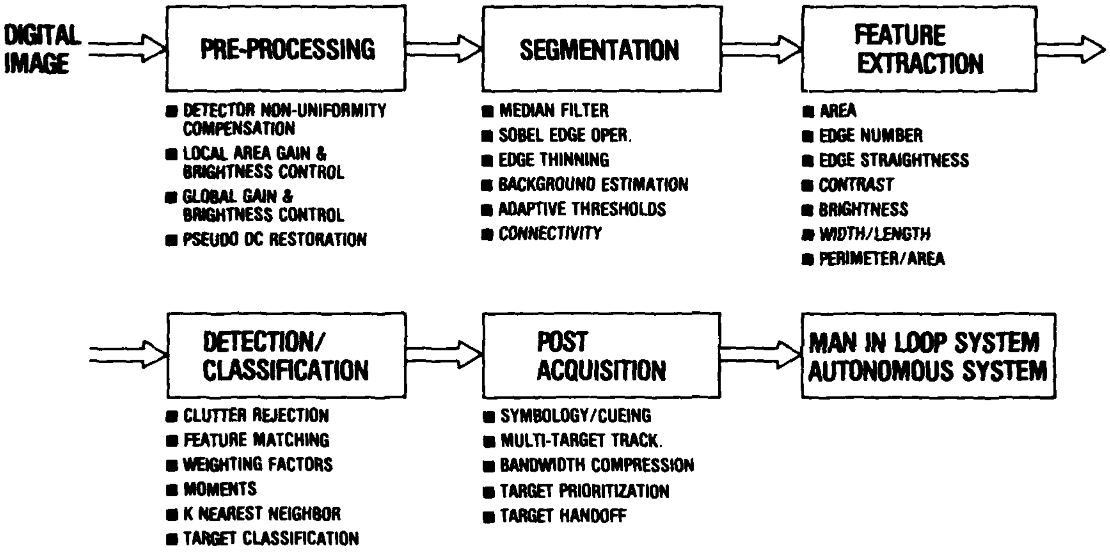

Figure 2-1. **TARGET ACQUISITION OPERATION**

3. TARGET TRACKING OPERATION

The need to track a moving target in real-time has been addressed in many forms in the past (Ref 5). In the target acquisition scenario, the detection process can include the tracking of target-like objects until they can be recognized. Target tracking in today's munitions and missiles utilize basic single mode approaches. One approach is the centroid tracker which establishes a window in which the centroid of the brightness image is calculated. The target lock-on is performed by the operator. If the target breaks lock, it is the operator who must reacquire it. A second approach is the correlation tracker in which image registration on a frame to frame basis in the track window is performed. Both tracker approaches have several shortcomings in the real-world scenario. Break lock occurs when target contrast becomes small and when clutter begins to compete with the target in the tracker window.

Advanced approaches to target tracking utilize multi-mode algorithms to improve system performance. A multi-mode "fire and forget" missile program combined both centroid tracking with correlation tracking and coast-mode tracking with an executive processor controller determining the dominant mode (Ref 2) during flight to target.

In a battlefield scenario including both air-to-ground and possibly ground-to-ground operations, a target acquisition system is bound to include several targets in its field-of-view at any given time. Military doctrine requiring high rates of fire, implies the ability to track multiple targets simultaneously. This problem has been addressed recently by several studies (Ref 6 and 7). The intelligent-tracker programs couple advanced target acquisition techniques with current tracker techniques to allow multiple-target-tracking in cluttered environments, with dynamic-target obscuration and low contrasts. Based on dynamic scene analysis, an approach included scene segmentation combined with detection and recognition functions. Then the objects in a new frame are matched to the scene model derived from previous frames. This scene model is capable of characterizing object and platform dynamics, target/background signatures and object occlusion (Fig 3-1).

Since the technique establishes a feature space and direction vector for each target, as a target goes behind some clutter or other target, it maintains the a priori knowledge that the resultant segmented object is made up of two objects. Then, when the target comes out from behind the obscurant, the tracker follows the target instead of locking onto the stationary obscurant (Fig 3-2). Future projections in hardware throughputs will make the evaluation of this concept in real-time hardware a reality.

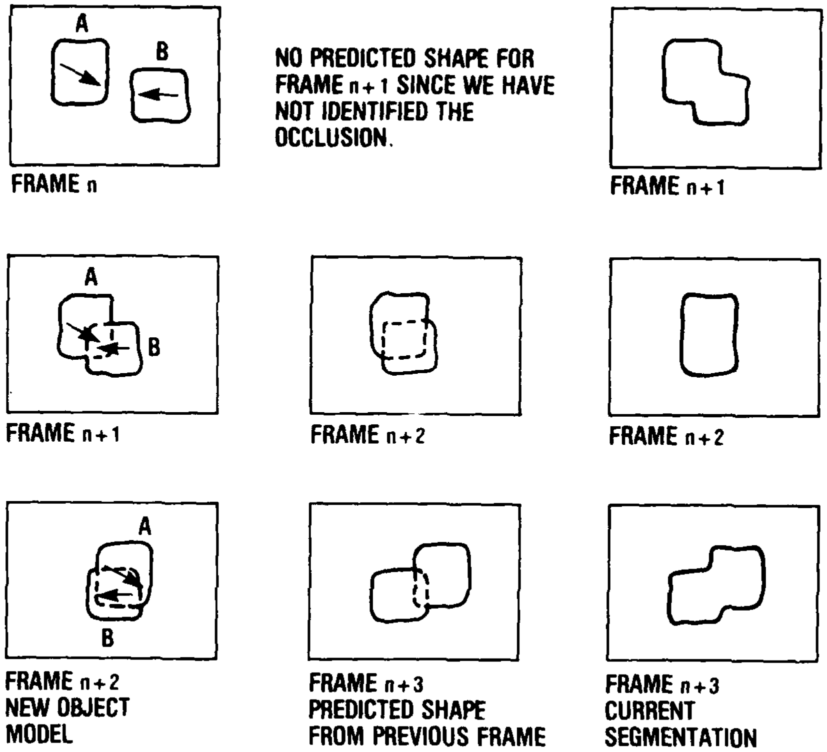

Figure 3-2. SEGMENTED TARGET AND CLUTTER WITH SHAPE PREDICTION AFTER OCCLUSION

4. MULTI-SENSOR SYNERGISTIC TARGET ACQUISITION OPERATION

Today the target-acquisition trends point to the multi-sensor arena for smart sensors of the future. The ability to extract and classify targets from FLIR imagery may reach the limitations of information content in the image itself. Therefore, multi-spectral sensors may well be required to extend feature space sensors to recognize targets at long ranges and/or in dense clutter scenarios in all weather conditions.

A variety of sensors exist which could be combined to give a robust target acquisition operation. As already discussed, the FLIR has at least two transmissive windows to operate in: MWIR which is the 3-5 micrometer window and LWIR which is the 8-14 micrometer window. Advanced sensors are being developed in both mechanically scanned, time delay and integration (TDI), and electronically scanned, stare configurations, which approach TV formats. Several other sensors are under development, such as, the CO2 laser-radar, millimeter wave radar, radiation homing, and acoustic sensors. With such a broad spectrum of sensors it is possible several may compliment each other to realize the truely autonomous smart sensor. Figure (4-1) shows the multi-sensor concept feeding a synergistic processor which operates the fire control system. An example may be the marriage of a millimeter wave radar sensor with an IR sensor. The dedicated preprocessing functions such as those listed in Section 2.0 for the IR target acquisition operation and the radar range and dopler operation could be performed in high speed front ends, both controlled by a central controller. A multi-target tracker could be integrated into the FLIR target acquisition operation with range, target coordinates, and special radar target signatures to make a more intelligent classification, prioritization and track. Other outputs could be derived such as image bandwidth compression for secure communication links, feature match for handoff to seekers, and navigation for flight control. Of course the two sensors could operate in series such that the FLIR is used in good weather and passive scenarios and the radar used in poor weather conditions along with the FLIR to assure all weather operations. All operations will require high information throughput hardware with an affordable cost factor.

5. PROJECTED NEEDS IN THE TARGET ACQUISITION SCENARIO

The projected applications in the autonomous target acquisition scenario are limited only by the imagination of the beholder. The autonomous air vehicle may take several directions. However let us consider the remotely piloted vehicle which may be properly renamed the autonomously piloted air vehicle (APAV). This vehicle may employ multi-sensors to perform the search/acquisition function. Also, it could perform the target extraction function with prioritization in which the target

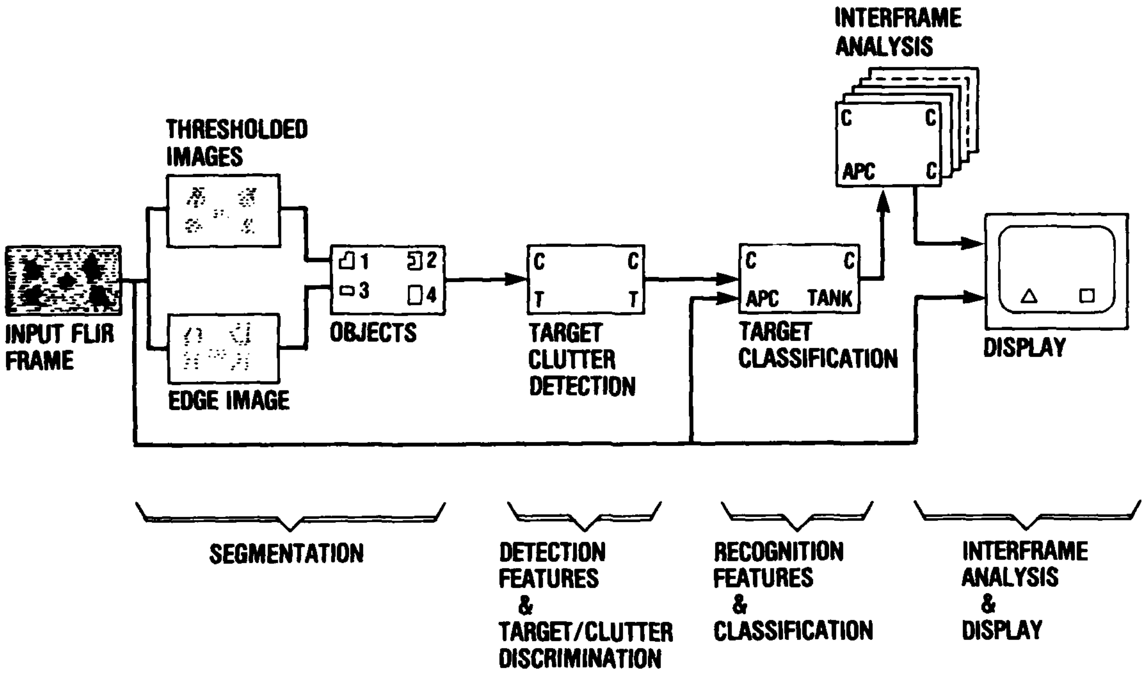

Figure 2-2. BLOCK DIAGRAM OF TARGET ACQUISITION OPERATION

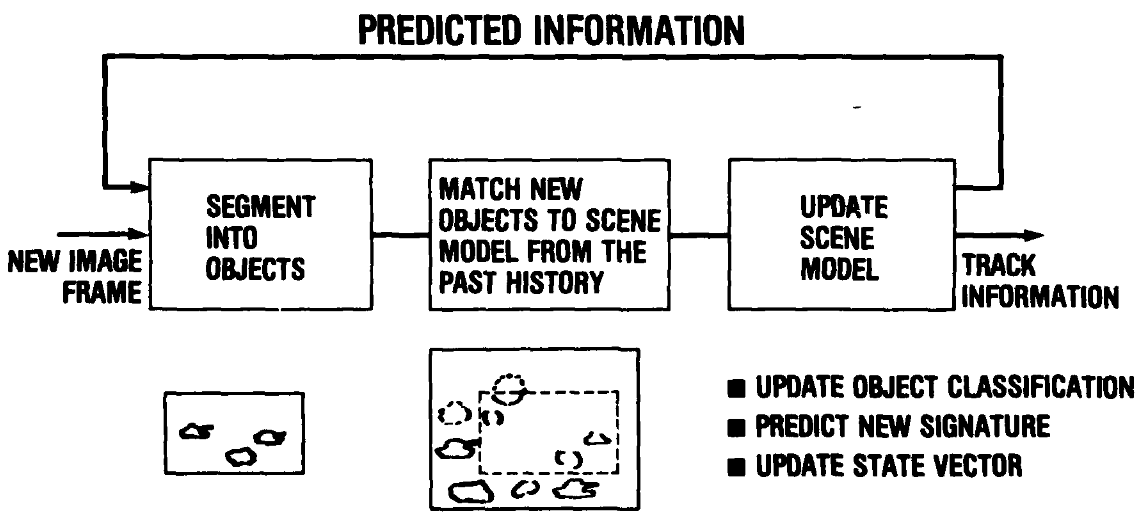

Figure 3-1. INTELLIGENT TRACKER CONCEPT

information is compressed and sent through a secure communication link. Feature matching could be utilized for navigation to bring fire control to bear in target designation and/or offensive operations.

The same types of operations could be applied to smart projectiles and/or missiles. The autonomous missile would acquire, prioritize and attack the highest prioritized target. It would have the ability to reacquire the target, if it should move out its field-of-view, and track the priority target without forgetting about the other targets in its field-of-view.

The autonomously piloted ground vehicle (APGV) could perform a variety of functions utilizing the operations discussed above. The APGV could operate as a scout in harsh battlefield environments. It could act as a decoy, operate as a resupply vehicle, act as a communication relay station, designate targets, and direct offensive fire power on to the targets.

6. PROJECTED TASKS FOR REAL-TIME TARGET ACQUISITION SCENARIOS

The types of operations discussed in Sections 2.0 through 5.0 may be realized in the future, but will they be affordable? Image processing hardware may take full advantage of the nearest neighbor types of operations by establishing massively parallel programmable architectures. This is already happening to some extent, but the high-density, high-speed integrated circuit technologies developing in this decade may make this more of a reality. By building in programmability with pipe-line structures to give hardware versatility, the high throughput functions for synergistic operations in real-time will be possible through software dedication.

The utilization of integrated multi-sensor configurations to perform the autonomous target acquisition operation is limited only by the ultimate costs and producability of such devices. As the technologies mature, the multi-sensor approaches may abound.

The challenge is established that as the sensor-dependent, target acquisition and tracking approaches are developed, the synergistic combination must be dealt with properly. The individual algorithms may require new insights with cross sensor dependencies establishing the feature spaces, thus allowing optimum separation of targets from clutter. As we see the hardware capabilities of tomorrow combine with the intelligence of the algorithms of today, we see a great need for advanced algorithms tomorrow. The possible new requirements in synergistic acquisition systems may possibly remodify the architectures of future hardware.

7. CONCLUSIONS

The real-time target acquisition and tracking operation may become the base from which several other operations will stem; such as navigation, target handoff, bandwidth compression and new synergistic multi-sensor approaches. The advancement of parallel-pipeline architectures conducive with image processing K-nearest neighbor types of operations may have programmability with high-information throughputs rates. The requirements for all-weather smart sensors could well require multi-sensor approaches. The synergistic approach may require a rethinking of the present-day algorithms for target acquisition and tracking. The inclusion of context-dependent target acquisition functions may improve the target tracking application and lead to artificial intelligence techniques applied to multi-sensors in the future. The new synergistic algorithm concepts could require entirely new signal processing architectures to efficiently handle the throughputs in real-time.

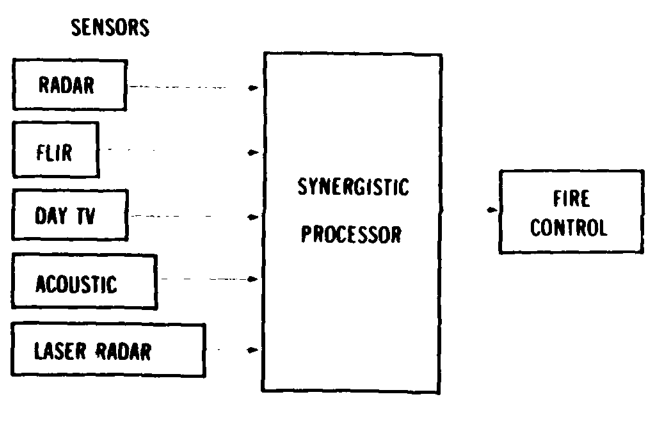

FIG (4 1) MULTI SENSOR TARGET ACQUISITION CONCEPT

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TACTICAL SYSTEMS APPROACH TO INTERDICTION OF 2ND ECHELON MOVING TARGETS USING REAL TIME SENSORS

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SUMMARY

This paper describes an integrated system architecture for the effective interdiction of second echelon ground forces which are advancing under the cover of intense EW and air defense protection. The proposed architecture is based on principles derived from control theory and present practice, and includes the use of advanced air-to-surface and surface-to-surface "quasi autonomous" attack elements operating in a complementary manner with stand-off target acquisition and track sensors. All of the necessary elements of such an advanced architecture are in fact in various stages of development today.

1. INTRODUCTION

The current trends in technology development programs indicate that it is possible to configure a NATO force structure that can effectively meet and suppress a numerically superior massed armor attack in Central Europe by the Warsaw Pact Nations. Key to this capability is the ability to interdict second echelon forces. The force structure able to perform this interdiction mission will necessarily include a combination of advanced long range air-to-surface and surface-to-surface missiles with advanced penetrator capabilities. The soft spot in current development programs aimed at this mission is that they form a proliferation of autonomous "target location and strike systems" each being designed to "win the war". These systems as currently planned would be directed by the present command and control structure.

As advanced sensor and strike technologies become available, it is prudent to reassess developments in this area and define an architecture that best unites the total ensemble of individual sensor and strike capabilities into an effective force. Any attempt to improve the present structure must be based on solid conceptual foundations. If we do not take a basically sound approach, whatever short term benefits we gain in applying current technology will be quickly overshadowed by operational chaos. An effective way to achieve maximum synergism between various advancing technologies is to integrate the individual capabilities into a cohesive force structure through advances in command and control. We propose using control theory as a basis to understand and improve present command and control structure. Before proceeding, it is important to review the requirements for successful interdiction of these second echelon forces as a basis for assessing our current technology and then ordering this technology into an integrated whole.

1.2 SECOND ECHELON FORCE INTERDICTION REQUIREMENTS

During a Warsaw Pact engagement, the second echelon and exploitation forces located within 50 to 150 Km from the FLOT are being trained to move very rapidly into the main battle when required to exploit a breakthrough. If not effectively impeded, total allocation of these forces into a breakthrough area would probably be accomplished in less than 5 or 6 hours. Across a 2 Army, 120 Km, front we are talking about stopping a force consisting of over 1,300 tanks and another 3 to 4 thousand armored vehicles including APC's, and artillery. To suppress these forces before they can effectively engage friendly forces, we assume that at least 40% would have to be destroyed. In terms of rates, this means we need to destroy at least 350 to 400 armored vehicles per hour. If the total system probability of kill per attack were 50%, we would need to engage roughly 800 targets of interest per hour. We feel this a minimum rather than an average number. Added to this scenario is the fact that these forces, and all second echelon command and control elements, communications nodes, logistics, etc., will be moving forward under advanced EW and SAM protection. From this one can scope the interdiction mission requirements. It is obvious that no single weapon system, no matter how sophisticated, could begin to accomplish this mission. It will take a mixed force, including attack aircraft and long range missiles.

From this scenario we define the critical requirements for interdiction systems to be:

1. Standoff or stealth penetration weapons delivery (for survivability)
2. Real-time targeting of the second echelon force elements (for effectiveness)
3. Detection-to-engagement response times of less than 30 minutes (for effectiveness against mobile targets)
4. At least 75% of the interdiction weapons systems must have a day or night and in weather operational capability (for availability)
5. The weapons must provide high P_K, and multiple target kill capability per launch/sortie (for effectiveness)
6. Penetrating attack systems must have a very low altitude single pass multiple target engagement capability (for survivability).

1.3 CURRENT INTERDICTION CAPABILITY AND TECHNOLOGY TRENDS

Against the postulated Warsaw Pact scenario, direct penetration to interdict the second echelon forces with today's aircraft would require ingress and egress at very low altitude and roll-back defense suppression tactics. Pop-up maneuvers for target acquisition and fire control must be limited to less than 30 seconds of exposure time. Based upon the response time of the current operational command and control elements, the resulting target location uncertainty, for all but stationary targets, is in the order of many kilometers by the time the aircraft reaches the target area. To attack moving targets, the penetrator must perform successive pop-up maneuvers above 200-300 meters and multiple passes for fire control. Since there are only a limited number of aircraft with capability for the terrain following (TF) and terrain avoidance (TA), that is required for nighttime and in weather operation, our current interdiction capability is not only very limited, but in many quarters the basic survivability and effectivness of those weapons systems that do penetrate is in question.

Because of this posture, added emphasis is being placed on the development of alternative interdiction capabilities. This development activity encompasses the application of both standoff surface-to-surface and air-to-surface missiles. Although these advanced weapon systems are very costly, they appear to be cost effective. The reasons are, simply stated:

a. These weapon systems have a high probability of reaching the target
b. They incorporate precision updated (quasi autonomous) INS navigation & guidance
c. They deliver multiple, high P_k terminally guided or unguided submunitions

When evaluating these missile systems against the present interdiction requirements, missile systems score very high. However even missile systems must be allocated against a target, and if the target is moving or even mobile the allocation and launch process is very time sensitive.

There are two basic points to be made at this time. First, using available technology, penetration attack with manned aircraft can achieve as high a measure of effectiveness. Second, to insure maximum operational capability and flexibility on a theater wide basis, we must upgrade our penetration attack effectiveness and survivability.

However, it is not a simple matter to build better attack aircraft, and it is becoming plain that adding more and more sensors to attack aircraft will soon reach a cost limit and is rapidly approaching an effectiveness limit, since as the penetrator's "safe" altitude decreases, its field of view also decreases. Both these limits can be sidestepped by the architecture we are proposing.

2. SYSTEM ARCHITECTURE

To improve the present and future capabilities of autonomous attack aircraft and move toward meeting the stated requirements, the interdiction mission should be treated in a systematic manner much as is done for the air defense mission. While the ground targets do not move as rapidly as aircraft, there are many more of them and their environment provides a much higher degree of concealment which makes the need for timeliness very similar. Rather than use the approach of sending autonomous aircraft into areas where enemy activity was reported, perhaps hours ago, a better approach is to use real-time remote sensors to closely direct the attacker to his target, or at least close enough so the attacker's own weapon system acquires the target. When taken to its most advanced form this allows the attacker to proceed with maximum stealth, significantly reducing or eliminating the vulnerable pop-up maneuver. The attacker would then have the advantage of knowing the precise position and velocity of his victim without the victim knowing when or from what direction the attack will come. In many cases low altitude delivery of either unguided or guided munitions could be made without the victim ever "seeing" the attacker. Given these benefits, the logical question is how can we achieve such a capability?

Ground attack missions have not had the benefit of a control system approach mainly because, until recently, technology has not provided the sensors needed to perform the real time long range detection and track functions. Without these real-time sensors the close relationship between a command and control system and a classical closed loop control system was not apparent. Now just as the advent of radar provided the eyes for closed loop air defense, advances in signal intercept and radar technology can provide analogous "eyes" to a ground attack system. These sensors also make it clear that tactical command and control is a control problem in the classical sense.

We will first address the impact that this advanced architecture places on the avionics.

2.1 ATTACK AVIONICS SYSTEM

To use any of the advances in sensor technology or even in command and control, the one piece of avionics that is absolutely mandatory is a robust, narrow band, possibly one way data link. This link between the command and control element and the attack aircraft is, in itself, perhaps the strongest asset to the manned penetrator mission. This real-time link between the command element and the attacker allows:

a. The pilot/weapons controller to receive updated target and threat information. This makes it possible to perform one pass attacks on moving or other time sensitive targets, perform effective multiple target engagements, and adjust ingress and egress routes during the mission (requirement for stealthy penetration, single pass attack).

b. Advanced sensors to pass real time information to the weapon system. This makes it feasible to use "blind bombing", remote lock-on of launch and leave weapons, or simply provide the attacker a clear view of his target while the attacker is still screened by terrain and foliage (requirement for real time information, high P_K).

As an example, given a good data link, the type of information that a moving target indicator radar could provide in real time to an attack aircraft is:

a. Time tagged target centroid coordinates. This allows the pilot/on-board weapons controller to know target direction and time to go regardless of the maneuvering of the platform.
b. Major axis orientation and extent.
c. Target shape factor.

These allow the pilot/weapon controller to choose the most appropriate attack aspect and make the best choice of weapons (i.e. attack a moving armor column where the terrain prevents the air defense from being effective with Wide Area Anti-armor Munitions). The target shape factor is especially important for area weapons that are designed for multiple kills such as the Wide Area Anti-Armor Munitions. These deploy in selectable patterns and maximum effectiveness is achieved by matching the weapon and target pattern.

Besides having a good data link, the attack aircraft must be capable of precision navigation and have reliable terrain following (TF) and terrain avoidance (TA) to allow 24 hour operation. An advanced TF/TA system should include the application of a stored coarse grid tercom type data base selected for safe ingress/egress routing. Incorporation of such a data base would give the pilot a real-time systems status check of actual vs predicted TF maneuvers as a function of position and time to go. Perhaps the most significant aspect of using a stored terrain data base is the fact that it would allow intermittent use of the active TF/TA radar. Current studies indicate that the time between transmissions could be as long as 5 seconds and the on times as short as .5 seconds. The net result is a significant enhancement in operational stealth. This same data base would also be used for precision navigation updates by correlating map data and position information at selected way-points. Currently available on-board position updated inertial navigation systems, such as the ARN-101 system under test and evaluation, offer sufficient accuracy, today, to support precision blind bombing against stationary targets. Figure 1, shows the low altitude attack proceeding along the selected series of way points which are also used for the navigation updates. The remote sensor provides both target and waypoint updates as required.

2.2 CURRENT EFFORT

Under the U S Assault Breaker Program, live demonstrations of low altitude penetration attack using updated inertial navigation and on-board computer controlled unguided ordinance weapon delivery will take place in 1982. For this demonstration a data link/transponder will be used on the attack aircraft to allow track of the penetrator by a stand-off radar. In this mode, the penetrator will receive position updates for both himself and the moving ground target from the radar through the transponder. This technique will be demonstrated, but requires active transponding from the penetrating platform. The only disadvantages of this approach are:

a. The transponder adds another small observable emission
b. Questionable update reliability because of terrain masking
c. Dilution of the stand-off target acquisition and track radar resources from the target area

Figure 2 illustrates the current Assault Breaker program demonstration activities. As shown, all radar data is downlinked via a wide band data link to a ground control and data processing system. In Figure 3, we show a more survivable "quasi autonomous" system that uses only narrow band data links to the ground and separate weapon data links from a command and control center.

2.3 COMMAND AND CONTROL

Today, tactical air operations are divided into counter air, close air support and interdiction. Two of these, counter air and close air support, are done in reasonable consonance with control theory. Interdiction is handled via daily tasking orders against (by necessity) stationary targets. We propose to handle all three similarly by handling the interdiction mission more like the other two.

The operational features that allow counter air and close air support to approximate a classical closed loop system are:

a. The resources are allocated a-priori to the mission not specific targets.
b. There are direct sensor inputs to the decision/control operations in these systems.
c. Final operation is allocated to an existing tightly closed loop (i.e. an intercepter or a forward air controller/attack aircraft).

The importance of these features is a natural result of looking at the command and control function from a control theory point of view. For a control system to function as expected it must have current information. This means that there is little or no time delay in the feedback elements. If such a delay is present (i.e. the information is too old), instability is likely in the classical case and confusion is almost certain in the command and control case. Delays in processing result in similar problems as with old information. While processing delay is no longer a real problem in most control systems due to the understanding of the theory and the speed of modern electronics, command and control loops often have many delays and time consuming manual interpretation and analysis procedures that prevent them from cycling in a timely manner.

To develop an effective command and control architecture for the interdiction mission we distilled the air defense system (part of the counter air mission and an effective real time system) into its essence. This essence is a closed loop control system. In practical form, the air defense system is a hierarchy of mostly closed loop systems that allocate, direct, and control forces in a real-time engagement. Figure 4 illustrates the kind of system we are talking about. Each of the elements of

such a system (AAA, SAM's or interceptors) is in itself a closed loop control system. Figure 5 is a diagram of a classical control mechanization with the exception that there are two sources of feedback, one directly from the output and one that senses the effect of the output on the environment.

When the names and labels on Figure 5 changed to those on Figure 6, the fact that a command and control structure is a closed loop control system becomes plain.

The structure that we derive is simply a hierarchy of control loops. The complexity comes from the interconnection of feedback elements. It is very easy to connect the output of a higher level loop to the command input of several lower level loops and generate a typical pyramidal command structure (Figure 7). This structure is not truly a closed loop system since the feedback path from the "environment" is not coupled to the high level loops. That is, each lower level loop can be functioning quite correctly according to the input from the higher level, but not producing the effect on the environment that the higher level is trying to achieve. The higher level loop would know that it was sending the directives it wanted, but would not know that they were in error.

The counter air operational structure solves this by using a surveillance radar at the the higher level loop getting feedback directly from the environment. Figure 8a shows this in block diagram form. It is a workable approach, well suited to counter air operations.

Figure 8b shows an alternative structure. In this approach, the feedback signals are connected directly from the lower loops to the feedback element of the higher loop. The data passed along is primarily the result of sensing the environment not the lower loop output. The function of the higher loop is to insure its commands to the lower loops are producing the desired results if not, to produce commands that will achieve the desired results. The structure of Figure 8b is suited to the interdiction mission, since the sensors employed by the lower loops (strike elements) return far more data over a larger geographical region than is needed by the lower loop for its immediate use. For example, PLSS collects location information on far more emitters than it can attack or will be directed to attack. This excess real-time data can be displayed (in very near real-time) in a higher level command element (CRC) to form the basis for a larger picture.

The major difference between the proposed structure and the one in use today is how the sensor data from tactical sensors is used. Present intelligence resources and especially the newer sensors not only have the field of view needed for effective command and control on a theater level, but the newer sensors also have the ability to guide weapons of various types including manned aircraft to a moving target or emitter from very long ranges. Such sensors as PLSS or PAVE MOVER are in themselves closed loop, real-time, detect-command-attack systems. The challenge is to effectively use the response speed of these systems to enhance the speed of the whole process. We propose that the sensors be controlled at the lowest (CRC/CRP) level especially if, like PLSS or PAVE MOVER, they have an attack direction capability. Note well that, all the data collected by lower command/execute elements is passed to the higher levels, but some is transformed into information and used immediately by lower command loops to execute the missions assigned to them by the higher command loops. We do not claim that this hierarchy of control loops structure is especially novel, only that it will allow the lower levels to react to changing situations very rapidly, and can support a high degree of complexity in actual operation. Certainly a cycle time of 10 to 15 minutes at the CRC level is possible. At the same time the higher level loops need not act so fast and can therefore take more time to process the added load of information. We have not specifically mentioned any sensor systems that have other than a real-time output (5 to 7 minutes) since this data is handled adequately at present and forms the context for the real-time data. Our point is that the real-time data should be used in real-time as its value decreases rapidly with time.

An important aspect of this approach is that by allocating resources a-priori to a mission the high speed control loop response of the executing level of command (generally the lowest) is decoupled from the slower allocation and directing levels. Again this mirrors what actually happens in counter air or close air support missions. From the National level where decisions may take weeks or months to move a wing, to the command post where the cycle time is typically hours or minutes to allocate aircraft, to the aircraft commander who acts in seconds to his missile which reacts in milliseconds, each control system cycles at an appropriate rate. After evolving the air defense system over time and knowing its capability, no one would suggest that all the levels down to the aircraft work on a 24 hour cycle, or that the national level make desisions in milliseconds.

To make our proposed structure a little more concrete we included Figure 9. This shows a portion of the tactical command and control structure including the proposed architecture. Note that both the Assault Breaker type closed loop sensor directed attack and the more loosely coupled attack structure are supported simultaineously. This makes maximum use of the wide field of view sensors such as PAVE MOVER and PLSS. Yet, even the loosely coupled attack is far more timely than the present structure allows.

Since there are representatives of many nations here, each with a different command structure we expect our proposed architecture, if it is adopted, will be implemented in many technically different ways. Therefore, we must also propose a method to measure the effectiveness of the system. The important parameter to use as a measure of effectiveness is the total time from first detection of an object to the time the first attack is hitting it as a target. Notice this includes the entire decision loop as well as avionics and weapon system performance. We feel that a time of less than 15 minutes is not only a desirable, but achievable, goal by 1985. In addition such metrics as the number of false attacks made or opportunities lost as a function of total opportunities per unit time could also be used. These are fairly easy to measure, but there are other metrics such as whether the targets attacked were the most important as viewed by the command and current doctrine. These are much harder to assess in a dynamic environment.

3. CONCLUSION

The strongest attribute of our proposal is it defines an architecture based on a proven concept and theory encompassing the entire problem.

In a dynamic situation, planning interdiction missions a day at a time for very expensive attack aircraft loaded with every conceivable sensor is not the best way to operate. We propose that the interdiction mission be handled more like the counter air or close air support missions and suggest that providing real time sensor data and resources directly to lower level centers for cooperative strike is a better method of operation. The opportunities that this creates in defense suppression, counter C^3 operation and synergistic attacks are numerous.

Reference:

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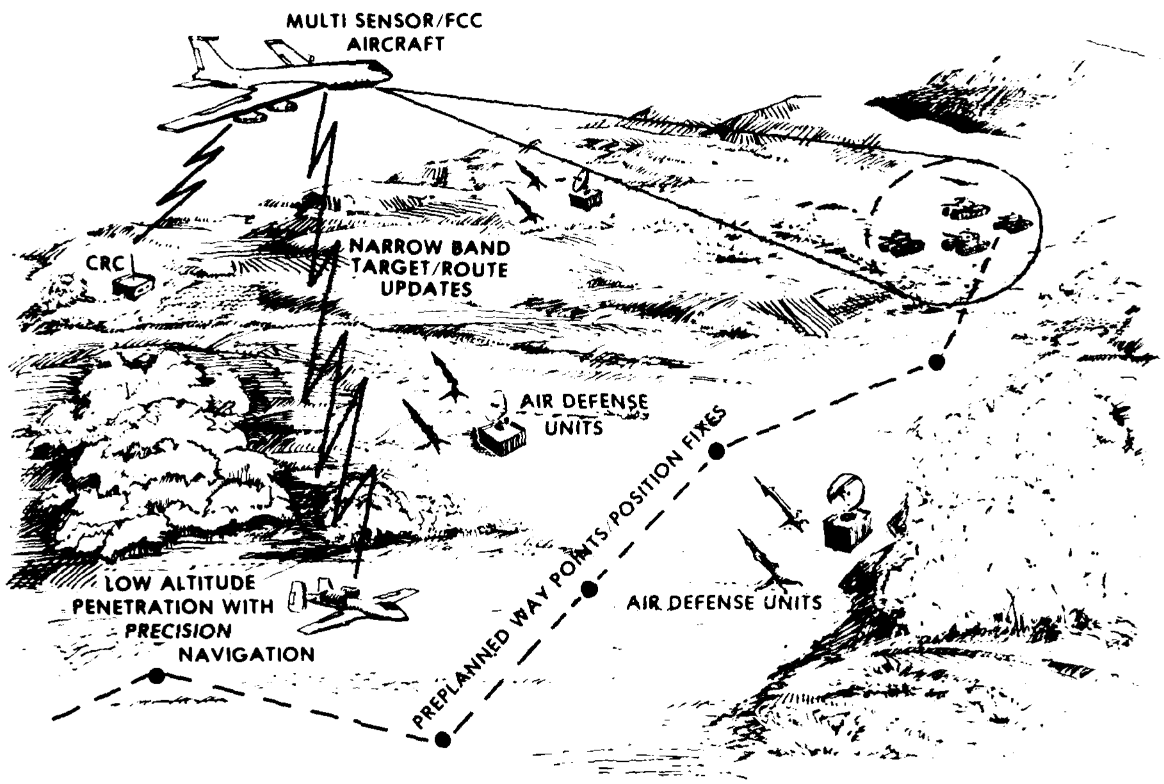

Figure 1. Cooperative Low Altitude Interdiction.

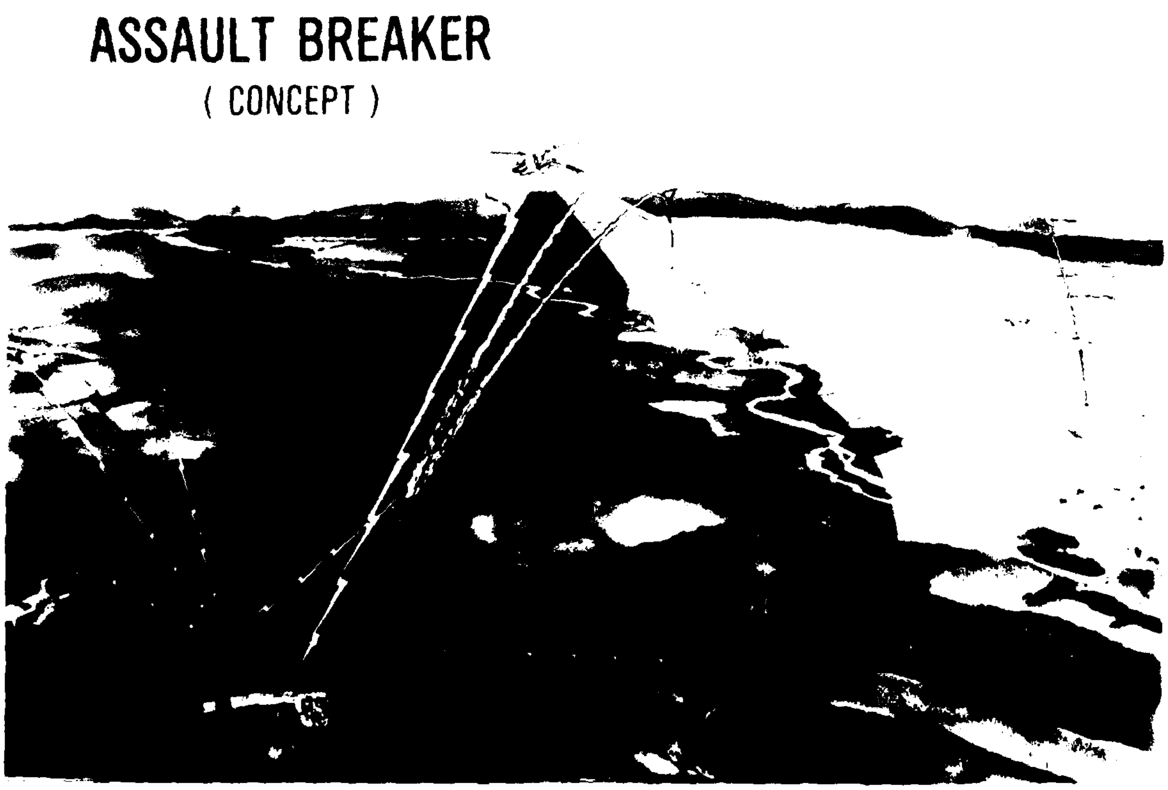

Figure 2. U. S. Joint Service Assault Breaker Concept.

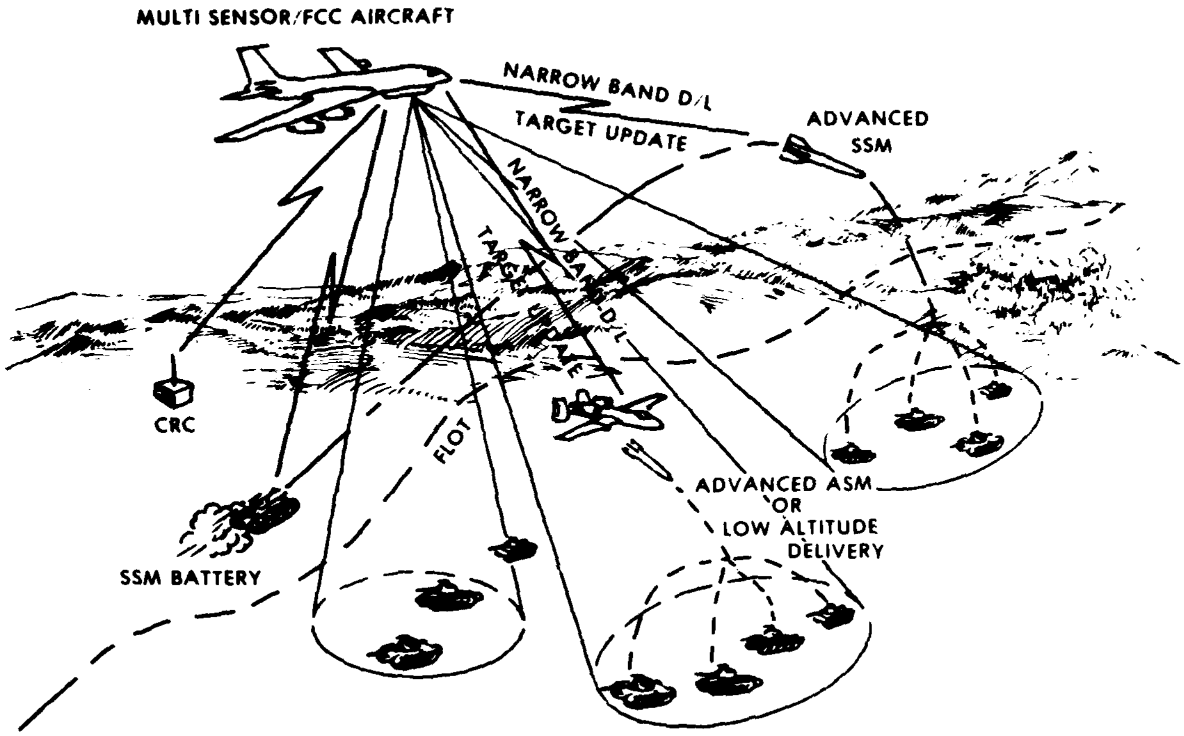

Figure 3. Advanced Integrated Sensor/Attack System.

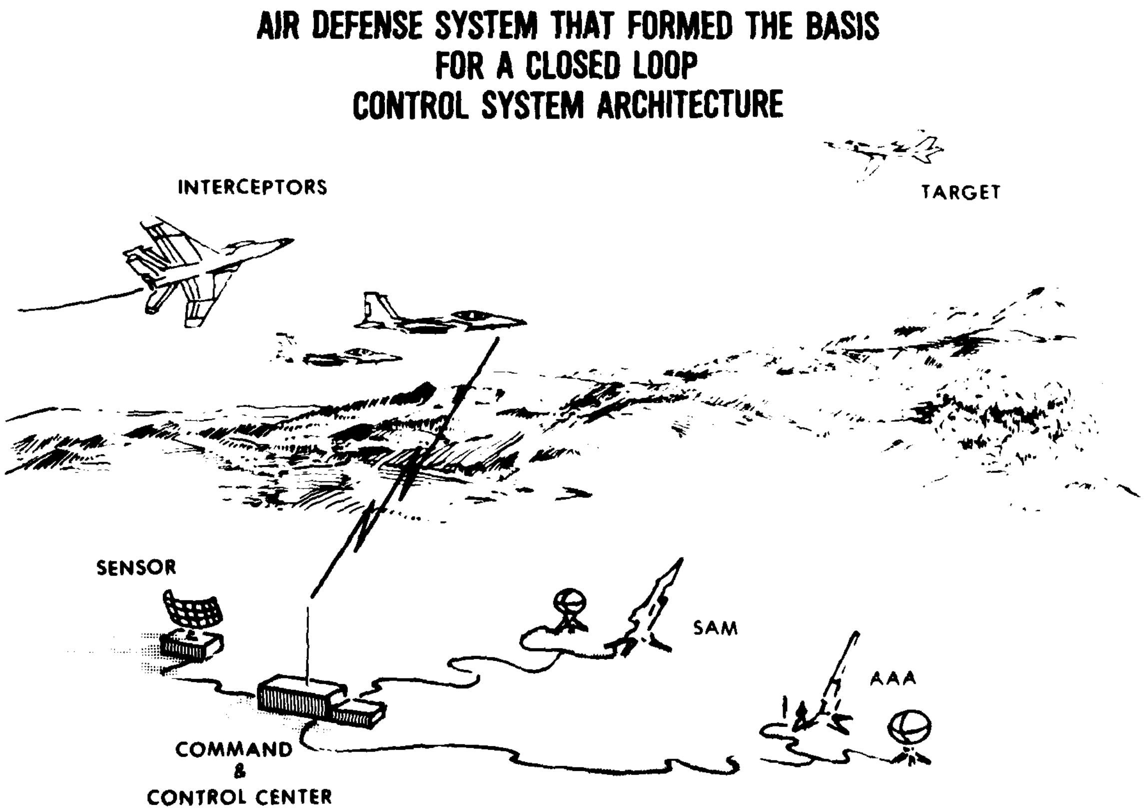

Figure 4. Conceptual Air Defense System.

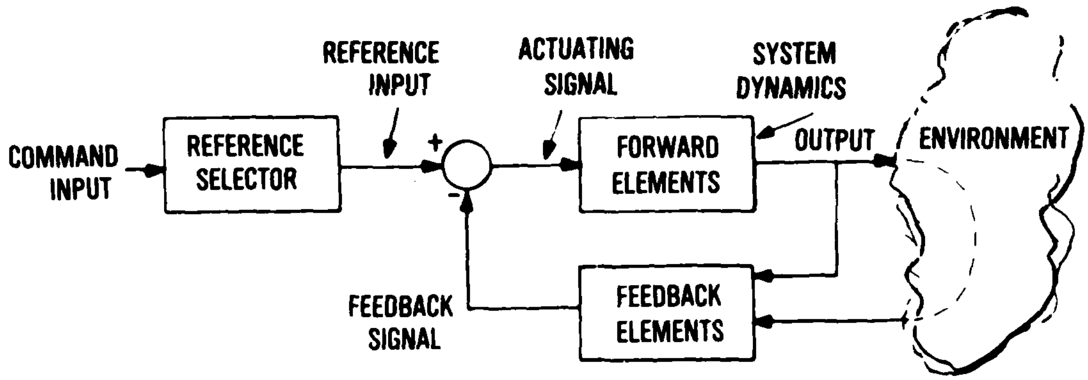

Figure 5. Classical Closed Loop Control System. "D'Azzo & Houpis"

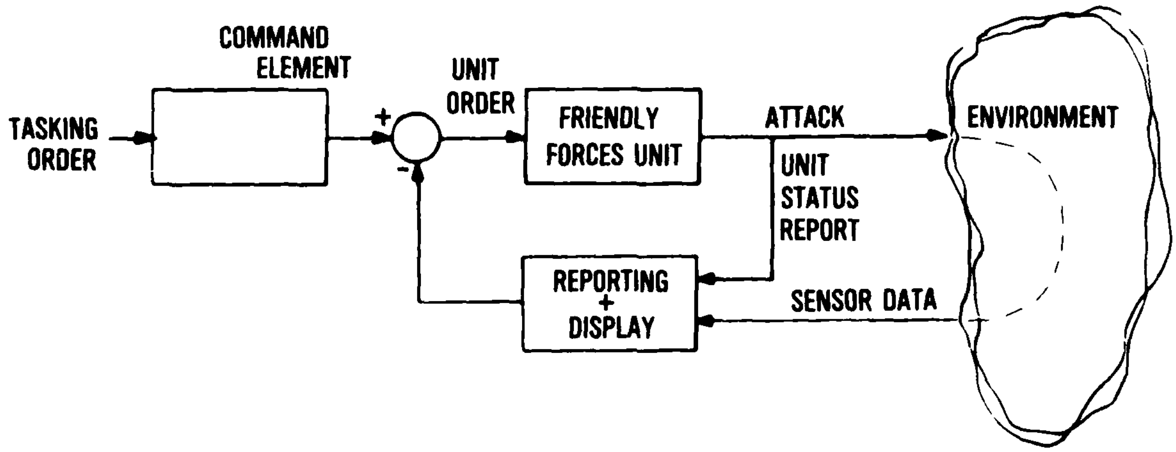

Figure 6. Closed Loop Command and Control.

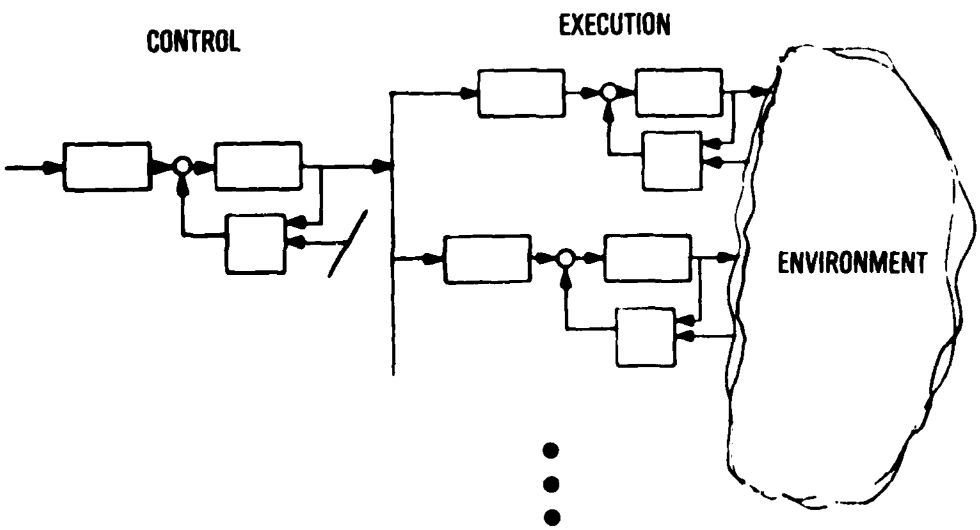

Figure 7. Stacked Control Systems.

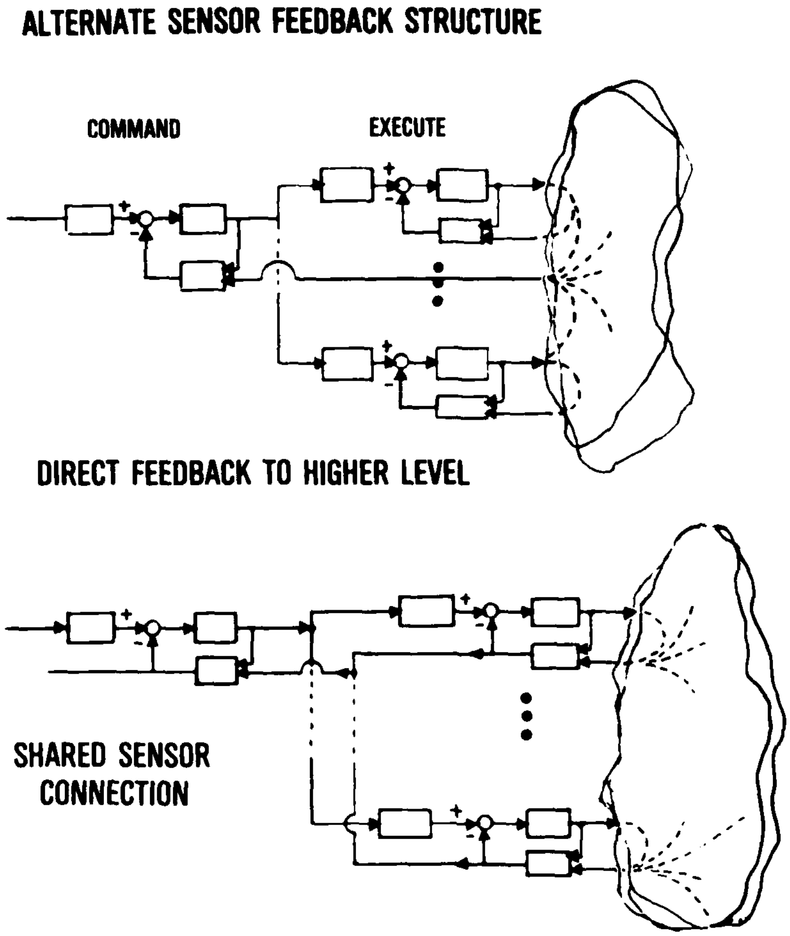

Figure 8. Sensor Feedback. 8(a) Top. 8(b) Bottom.

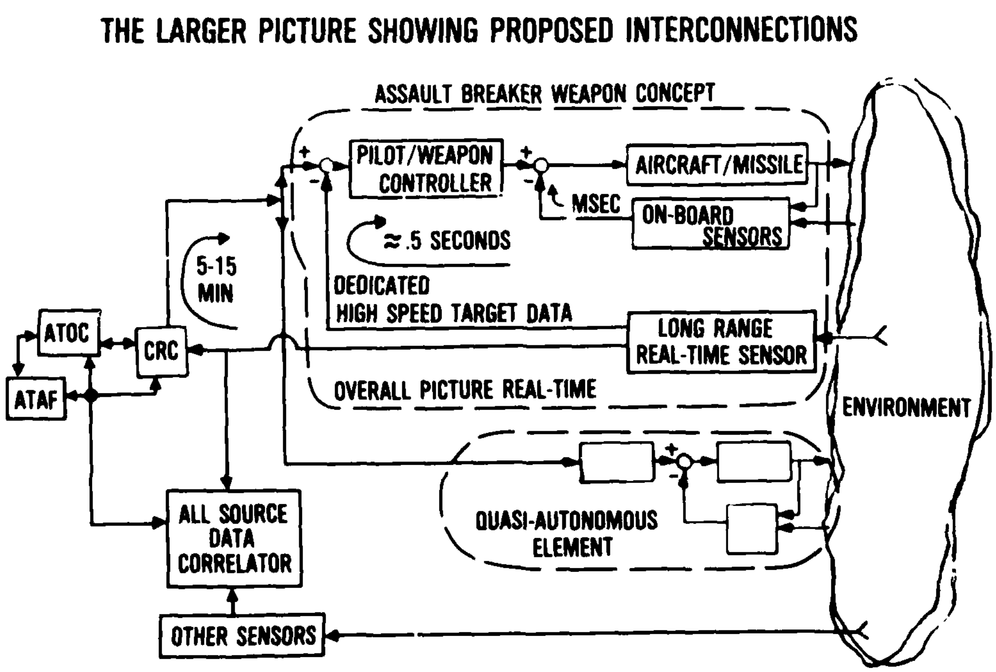

Figure 9. Advanced C^3 Architecture.

A CONTRIBUTION TO AUTONOMOUS VEHICLE DETECTION BY A MOVING SENSOR

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1.0 Summary

An algorithm is presented which is capable to detect autonomously moving vehicles seen by a moving sensor. The detection is based on the analysis of the motion vector field within the field of view. Examples are given as the algorithm determines the motion vector field for translation, rotation, and focal length changes. Promising results have been achieved for the autonomous cueing of a moving tank in a landscape environment.

2.0 Military significance

An essential task of the Nato forces is the ability to stop attacks of hostile tanks. It is therefore desirable to have advanced weapon systems which allow to combat armored vehicles even when they are beyond the range of sight. "Autonomous seekers", performing the full sensoric task of the human operator should make that possible.

Such a seeker has to perform the task of detection, classification, and tracking autonomously. It can be expected that it is equipped with an imaging infrared sensor to be able to extract target relevant features even under adverse weather conditions.

The autonomous detection, segmentation, and classification of tanks is a rather sophisticated task. At the present state of technology submunitions will not be capable to perform it in the near future. A possible solution might be to use an advanced sensor in a carrier missile which cues the target automatically and assigns the targets to the submunitions before their release. The submunitions are equipped with much simpler sensors performing "only" the tracking of the assigned targets. Thus autonomous seekers have to fulfill the entire sensoric task of the human operator.

At the present state of our knowledge about target recognition the detection can only be performed, if easily and fast extractable features are used that correspond to the physical properties of tanks. These properties are high temperature, high microwave reflectivity, and motion. To perform the classification of the targets these properties will not be sufficient. Shape parameters will be required which only can be computed after the segmentation of the targets.

As it is well known from the field of time-varying imagery, motion is a very useful property to support the segmentation process /1/. The research described in this contribution investigates the feasibility of using relative motion of vehicles against the background as the relevant feature.

3.0 Problem

The task is to perform the automatic cueing of moving objects in a natural environment. Additional problems arise if the sensor itself is moving. Possible movements are panning and tilt of the camera as well as rotation and movements towards the target resulting in scale factor changes. These kinds of motion lead to non-homogeneous diplacement vector fields in the image plane due to perspective distortion.

In the field of image sequence analysis, very sophisticated methods of analysing image differences are known (e.g. /2/), however they require a stationary sensor.

Extraction of certain features from each image of a sequence and tracking their position for consecutive images in order to determine a displacement vector field seems to be a promising approach /3/. Objects in motion relative to the background may be detected by a set of significantly different vectors compared to their neighborhood.

The features we use are straight lines approximating edges in the original image. They have the advantage of invariant properties under different illumination conditions and allow a precise displacement determination.

We already presented a method to determine the general motion of the field of view by applying a majority voting procedure for the possible displacement vectors /5/. A

tor fields that can be expected for an airborne sensor /6/. This paper will give an overview of the method and will present promising results for the detection of moving vehicles.

4.0 Preprocessing

The algorithm to extract straight lines from the image was originally developed for the detection of man made objects in aerial photographs. Details are given in /4/.

The first step is the extraction of high contrast points which give evidence to edges of objects or structures in the image. This is done by scanning the lines for dark-bright transitions. After a slight hysteresis filtering the original (one dimensional) brightness function is approximated linearly between maxima and minima. The slope of the line pieces together with the distance of the minima and maxima and the brightness level define a contrast measure. Only the one pixel between two extreme values of the brightness function where the slope is maximal (i.e. the second derivative vanishes) is assigned that contrast value. This results in a contrast image which appears very familiar to the human observer and does not require any further skeletonizing as it is known e.g. from the Sobel filter. In fact this edge operator was designed to resemble the frequency response of the human visual system.

The same procedure is repeated for bright-dark transitions and for both transition types in column direction. The resulting contrast values are stored in four distinct contrast images. Fig. 1 shows an overlay of all four contrast matrices computed from the original image in Fig. 2.

5.0 Feature extraction

The purpose of storing the contrast matrices in four distinct images is to avoid confusion between bright-dark and dark-bright edges during the line fitting procedure. It starts with a point of high contrast value and tries to merge points nearby to a straight line. The local search and merge process is repeated until there are either no more points available or the total regression error of the line exceeds a given threshold. This termination condition avoids merging curves that are too fuzzy to straight lines.

The lines are described by their centroid position, by their length, and the angle against a reference direction. These parameters represent a feature vector which is stored in a feature list. The visual representation of the lines extracted from Fig. 2 is given in Fig. 4. Note that the feature extractor is not designed to give the best visual display of the original image but to allow an effective displacement determination.

6.0 Motion determination

The stored feature list represents a symbolic description of the original image resulting in a data reduction. All further processing is performed only on these lists. Holding the original images in computer memory is therefore dispensable.

The motion determination algorithm is demonstrated on a scene showing an aerial photograph of the Frankfurt airport. Figs. 2 and 3 show the first and the ninth image of a sequence where the camera was rotated 32 degrees. Figs. 4 and 5 visualize the extracted line segments.

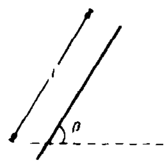
Each entry of the feature list of an image is matched with the features of the following one within a certain local neighborhood. The centroids of the line segments in consecutive frames determine a presumable displacement vector. During the matching procedure only lines originating from the same contrast matrices are compared. Since the polarity of an edge does not reverse its sign immediately under usual illumination conditions, this approach avoids the interchange of inner and outer boundaries of objects and reduces computing efforts and memory requirements.

Displaying the presumable displacement vectors calculated from the rotated airport scene results in the scheme shown in Fig. 6. It shows dense clusters of vectors which locally conflict with each other. Inconsistencies arise if more than one vector emerges from the same position or more than one vector points to the same feature position.

The fundamental problem is now to decide which feature of image 1 corresponds with a given one of image 2, or in other words which is the "true" feature to be associated. The correspondence decision in the algorithm described is based on the similarity of the features.

7.0 Similarity measure

To express similarity between features, a similarity measure was defined which depends on the lengths and the slopes of the features to be associated. The definition of the measure is given in the equations below.



$$A_\beta(\beta_1, \beta_2) = \max\left(1 - \left|\frac{\beta_1 - \beta_2}{15°}\right|, 0.1\right)$$

$$A_l(l_1, l_2) = \min\left(\frac{l_1}{l_2}, \frac{l_2}{l_1}\right)$$

$$A_{tot} = A_\beta \cdot A_l$$

$$0 < A_{tot} \leq 1$$

One part depends on the differences of the slopes, expressed as angles against a reference direction, compared to a maximum angular deviation which was chosen to be 15 degrees. The maximum operation avoids negative values and it clamps the angular similarity to a value of 0.1 .

The similarity with respect to the lengths of the line segments considers the ratios of the two lengths. The minimum operation chooses the one ratio which is less than one.

The total similarity coefficient is given as the product of the two distinct measures yielding a number between one and zero. As a result similarity coefficients near one assure the two features to be associated having very similar lengths and slopes.

8.0 Correspondence decision

Under the assumption that the straight lines approximating edges change slowly from frame to frame, it is reasonable to assume that the true displacement vector connects two very similar features. Therefore a good estimate of the displacement vector field is achieved by local maximization of the similarity coefficients, with the constraint to avoid physically meaningless constellations .

Fig. 7a illustrates a cluster of presumable motion vectors. The numbers attached to the vectors are the similarity coefficients calculated from the feature pairs. The strategy of removing inconsistencies in the vector field is to look for the highest similarity coefficient in each cluster and to remove all conflicting vectors. This is repeated until all contradictions have been eliminated (Fig. 7b).

As the example shows, it may happen that there remain features which are not associated with a partner in the following image. This may be due to changes of the illumination of the scene, errors of the feature extractor, or due to occlusion by objects in motion. These are actually the problems an algorithm that analyzes image sequences of natural scenes, has to cope with.

Applying the described procedure to the vector field in Fig. 6 results in the field shown in Fig. 8. The rotational symmetry of the vector field and the relationship between its magnitude and the distance from the center of rotation is apparent. However, there still exist vectors conflicting with the general direction of their neighborhood. These mismatches are caused by features which have changed too much to be considered as the most similar ones.

In order to increase the reliability of the vector field the locally oriented algorithm has to be exploited to consider also the development of the features in the time domain.

9.0 Feature tracking

The goal of the determination of the displacement vector field of a scene observed by a sensor in motion is the detection of objects moving relative to the background. A moving object represents itself in the image plane as a set of vectors which are significantly different from the vectors of the nearby background. In order to keep the false alarm rate low, the motion vectors used for the target/non-target decision should be as reliable as possible.

If it is possible to track the position of a feature for the duration of several frames, the resulting motion vector gains much more confidence, and random position jitter will be smoothed.

By repeating the correspondence procedure for each image pair and linking the motion vectors, the displacement vector field for the duration of several frames is obtained, however only those features are contributing that can be extracted in every single frame. The result for four consecutive images is shown in Fig. 9. Fig. 10 displays the

motion vector field for six consecutive frames and Fig. 11 for nine images. The number of vectors decreases with observation time due to the restriction that a feature has to be found repetitively in each picture. Simultaneously the reliability increases.

The method presented is not only capable to handle rotation but can cope with scale factor changes too, as the following example demonstrates. Figs. 12 and 13 show the first and the fourth images of a sequence where the focal length of the camera changed continously. Figs. 14 and 15 are the corresponding line drawings of the original images. The calculated displacement vector fields of two and four consecutive images are depicted in Figs. 16 and 17. Again the regular orientation of the field as governed by the laws of geometrical optics is evident.

10.0 Motion vector clustering

The vector field obtained by tracking features for the duration of several frames may be used as the input for a motion based segmenter. This is demonstrated for the case of a traversing camera. Fig. 18 is the first image of a sequence showing a tank moving from the right to the left. The background is moving into the opposite direction due to the camera motion. The calculated vector field for the duration of three consecutive frames is given in Fig. 19. Clearly visible is the cluster of vectors in the right part of the image which belong to the moving tank.

Generally a moving object represents itself on the image plane as a cluster of almost equally directed vectors. As a result the motion based segmenter tries to find motion vectors which have neighbors nearby with approximately the same magnitude and direction. This is done for each vector and afterwards all the vectors are merged to clusters. This approach allows to follow smooth changes of the vector field but due to the similarity constraint it will not merge object and background clusters. The clustering process will stop either if there are no more vectors nearby available or if it encounters discontinuities of the vector field.

The results of the cluster procedure are several clusters which are described by the number of contributing vectors, their minimal and maximal row and column coordinates, their mean displacement vectors, and the two standard deviations of the displacement vector coordinates. Clusters containing less than three vectors are rejected. Fig. 20 illustrates the computed vector clusters by their minimal surrounding rectangles in row and column direction. Two clusters cover the vehicle, the remaining five belong to the background.

11.0 Segmentation

Fig. 21 shows the mean values of the motion vectors plotted in the velocity plane. The crossed bars symbolize the two components' standard deviation. Obviously the set of clusters is composed of two distinct classes. The clusters of each class may be interpreted as to originate from the same distribution of vectors within the statistical uncertainties.

The decision as to which class represents the vehicle and which the background, is merely based on the number of vectors contributing to it. This is validated by the fact that the moving object covers a much smaller area in the image plane than the background. Fig. 22 shows the result of automatically choosing the two clusters belonging to the vehicle.

This result illustrates the present state of the project. The algorithm is currently improved to detect moving vehicles for more complicated sensor motions as e.g. rotation and zoom.

12.0 Conclusions

An overview of the different stages of the algorithm for automatic detection of moving vehicles is given in Fig. 23. It extracts straight lines from each consecutive image which are stored in a list representing a symbolic description of the original image. A first estimate of the motion vector field is accomplished by matching the entries in these lists. In order to avoid physically meaningless constellations, a similarity coefficent is computed comparing the two features to be associated. Locally maximizing the similarity measure results in the rejection of inconsistent vectors.

Taking into account the motion vectors calculated from previous images enables the tracking of features for the duration of several frames. The results are motion vector fields with increased reliability. By clustering similar vectors considering their local neighborhood and evaluating their statistical variations a segmentation of the moving vehicle could be performed.

The method presented is not restricted to straight lines as features. Using another feature extractor and redefining the similarity measure is sufficient to adapt the matching and segmentation algorithm to other data sets. Investigations on a suitable i.e. stable feature for infrared images are currently performed in our research establishment.

Examples of image sequences picked up by a traversing, rotating, and zooming sensor are given to illustrate the ability of the algorithm to handle even complicated motions. Demonstrating the present state of investigation, the automatic cueing of a moving tank in landscape environment is shown.

The algorithm is currently being improved to detect moving objects for more complicated sensor motions.

13.0 References

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Acknowledgement: This work was supported by the Ministry of Defence

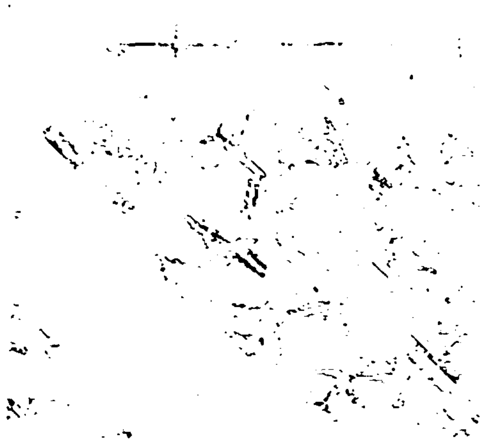

Fig. 1: Contrast image computed from Fig. 2

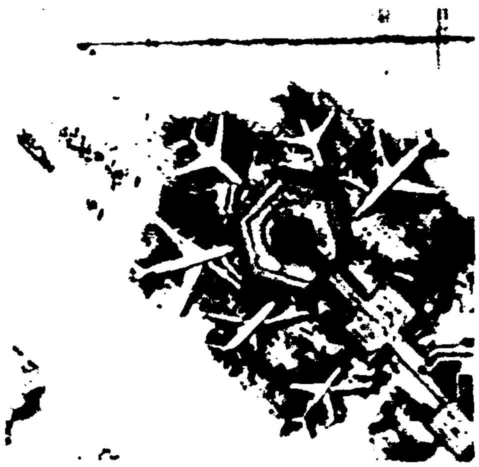

Fig. 2: First image of a sequence

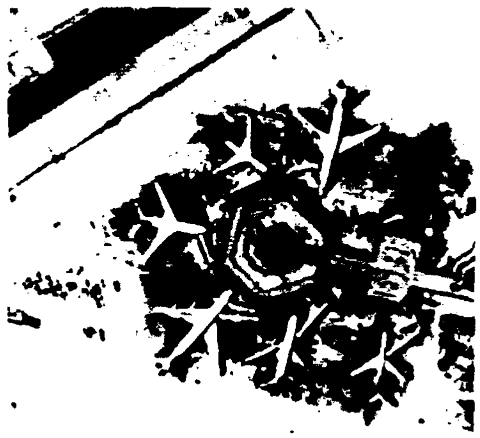

Fig. 3: Ninth image rotated 32° against Fig. 2

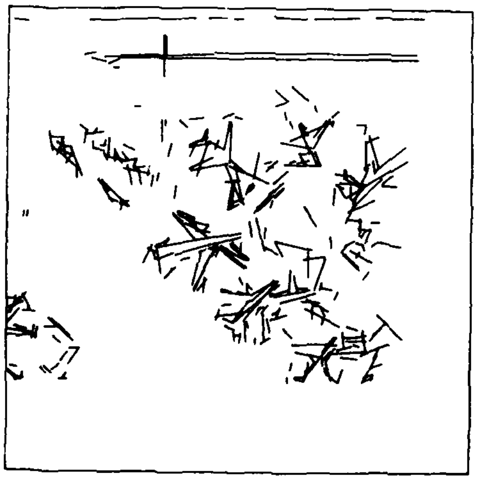

Fig. 4: Line segments extracted from Fig. 2

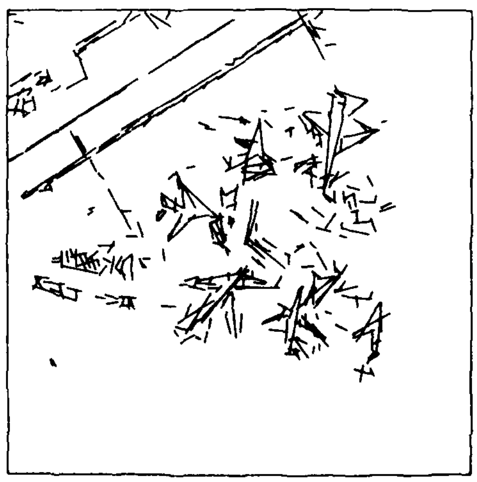

Fig. 5: Line segments extracted from Fig. 3

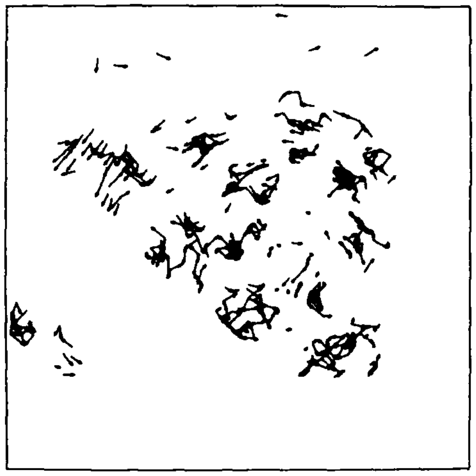

Fig. 6: Presumable vector field

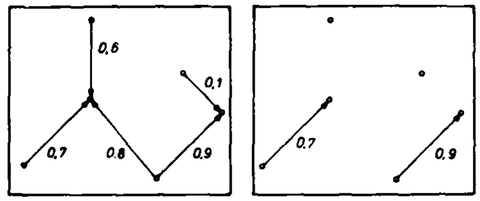

Fig. 7: Vector cluster with attached similarity coefficients

Fig. 8: Vector field after correspondence decision

Fig. 9: Vector field for four consecutive images

Fig. 10: Vector field for six consecutive images

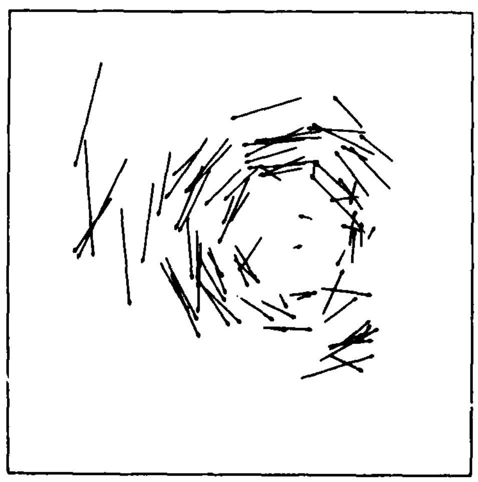

Fig. 11: Vector field for nine consecutive images

Fig. 12: First image of the zoom sequence

Fig. 13: Fourth image of the zoom sequence

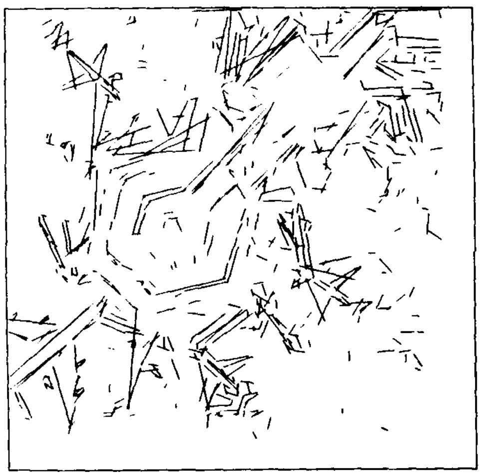

Fig. 14: Line segments extracted from Fig. 12

Fig. 15: Line segments extracted from Fig. 13

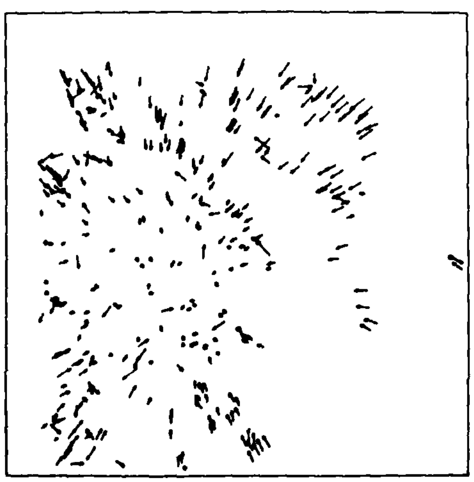

Fig. 16: Vector field for two images

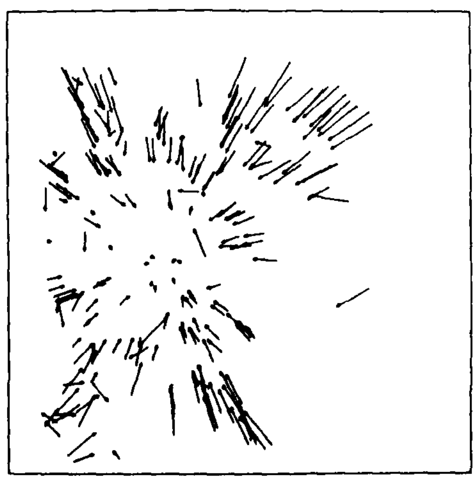

Fig. 17: Vector field for four consecutive images

Fig. 18: First image of the tank sequence

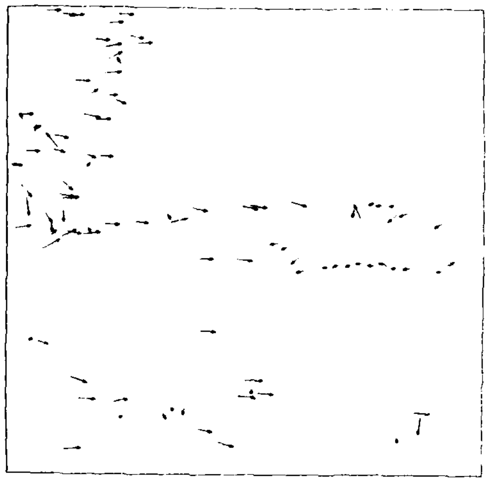

Fig. 19: Calculated vector field for 3 consecutive images

Fig. 20: Vector clusters projected into the third image

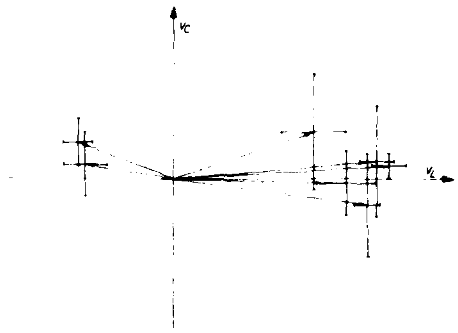

Fig. 21: Mean values of the vector clusters with their component's standard deviation

Fig. 22: Result of autonomously cueing the moving tank

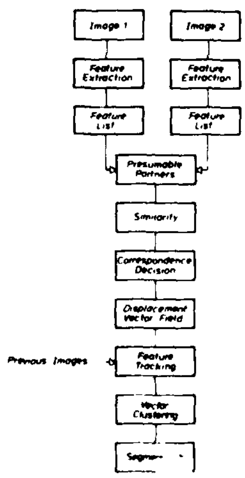

Fig. 23: Flow chart of the algorithm

MULTISENSOR AND MULTIMODE INTEGRATION - A PERSPECTIVE

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SUMMARY

The expanding development of targeting and fire control sensors from radar to television, forward looking infrared, carbon dioxide laser, and millimeter wave, creates a number of critical questions for the weapon system designer. How many and which types of sensors should be chosen? How should they be physically and functionally integrated? How can the system effectiveness be evaluated? This paper presents a simple probabilistic approach for examining some of the factors which bear on the questions and makes a prognosis of the prospects for achieving satisfactory answers.

Analyses and simulations of various multisensor and multimode options for air-to-surface missions indicate the potential for significantly reduced operator workload and increased mission effectiveness, especially in diverse weather and countermeasure conditions. These improvements result from systematic and synergistic integration of various sensors and modes, with emphasis on automatic target recognition and information fusion. The translation of these improvements, from simulation results based on a multiplicity of assumptions to performance results based on hardware and software validation is a formidable challenge, however, the technology can be matured within the next three to five years.

1. INTRODUCTION

The operational scenario generally postulated for the air-to-surface mission in the 1985 - 1995 time frame assumes attack, in day, night, and weather conditions, of a mix of targets, in a battlefield environment replete with countermeasures, obscurants, and a devastating array of defensive weapons. There is a growing realization and acceptance among the operating forces and development community that the success of a mission in this scenario is critically dependent on the development of advanced avionics and weapons. Primary emphasis is being put on weapons which provide multiple kills per pass and on avionics to provide supporting targeting and fire control functions.

Although radar has traditionally been the primary sensor for these functions, the requirement to identify and discriminate between small tactical targets for precision weapon delivery has led to the development and use of a variety of electro-optical sensors. Television (TV) and forward looking infrared (FLIR) systems are in operational use in many armed services and carbon dioxide (CO_2) laser and millimeter wave (MMW) radars show the potential for performing many targeting and fire control functions. With the many functions to be performed and the growing number of sensors available, the questions arise as to which and how many to use, what modes should they have, how should they be integrated, and what is the performance improvement over current systems? The purpose of this paper is to examine some of the factors which bear on the questions and make a prognosis of the prospects for achieving satisfactory answers.

2. SENSOR SELECTION

The air-to-surface mission generally assumes attack against stationary, moving, and concealed targets under diverse weather and countermeasure conditions, the varied effects of which suggest that multimode and multiple sensors may be necessary. Should this be the case, a rational, systematic sensor and mode selection process is needed, and it becomes necessary to address the questions identified above. To examine some of the factors which impact the answers, consider the task of selecting sensors and modes to accomplish target recognition (detection and classification) in an interdiction mission against armored vehicles. When the specifics of the scenario have been defined (aircraft, weapons, weather, countermeasures, etc.), the sensor selection process can be started. The sensor selection process begins with an analysis of data requirements. The data requirements for target recognition revolve about the ability to observe or measure specific target signatures or discriminants, and to process the data to arrive at a declaration of detection or classification with a very high probability of success. Table 1 is a representative listing of likely discriminants for detecting and classifying tactical armored vehicles. Once likely discriminants have been identified, they can be analyzed, evaluated, and ranked in order of usefulness, and sensors capable of making appropriate measurements in the specified weather and countermeasures conditions can be identified and assessed. Table 2 shows a rank ordering of the most useful of the discriminants from Table 1, and provides a qualitative assessment of the capabilities of various sensors to make appropriate measurements under ideal sensor operating conditions. This assessment must be refined by considering the impacts of the scenario dependent obscurant and countermeasure conditions. This is a significant task, but one which can be accomplished.

● EXTENT - RANGE - AZIMUTH - ELEVATION	● RADAR SIGNATURE - REFLECTIVITY - ACTIVE - PASSIVE - JAMMING
● RESOLUTION - PATTERN - SHAPE - TEXTURE	● ELECTRO-OPTICAL SIGNATURE - REFLECTIVITY - ACTIVE - PASSIVE - FLASH
● DOPPLER SIGNATURE - VELOCITY - SPECTRUM	● OTHER EMISSIONS - IGNITION - RADIO - AUDIO - CHEMICAL/ODOR

TABLE 1. TARGET DISCRIMINANTS

TARGET DISCRIMINANTS	RADAR		LASER RADAR		FLIR		MMW		ELECTRONIC SUPPORT MEASURES	
	D	C	D	C	D	C	D	C	D	C
EXTENT										
RANGE	E	F	E	G	-	-	E	G	G	-
AZIMUTH	F	F	E	G	E	G	G	F	G	-
ELEVATION	F	F	E	G	E	G	G	F	G	-
RESOLUTION										
PATTERN	G	F	G	F	G	F	G	F	-	-
SHAPE	G	F	E	E	E	E	G	G	-	-
TEXTURE	-	-	-	E	-	E	-	-	-	-
DOPPLER SIGNATURE										
VELOCITY	E	-	E	-	-	-	E	-	-	-
SPECTRUM	-	F	-	E	-	-	-	G	-	-
REFLECTIVITY	E	F	-	E	-	-	-	G	-	-
EMISSIONS										
RF	G	-	-	-	-	-	G	-	E	G
THERMAL	-	-	-	-	G	-	-	-	G	G

E = EXCELLENT G = GOOD F = FAIR D = DETECTION C = CLASSIFICATION

TABLE 2. SENSOR DISCRIMINANT UTILITY ASSESSMENT

To gain some insight into the complexities of the sensor assessment and selection process, assume that for all available sensors, sensor i operating in mode (discriminant) j will successfully perform a desired function with probability P_{ij}. Then, assuming independence of each P_{ij}, the probability of successful function accomplishment by at least one sensor in some mode, P_s, is given by

$$P_s = 1 - (1-P_{11})(1-P_{12})\ldots.(1-P_{ij})\ldots(1-P_{nm})$$

where $i = 1,2,3,.., n$ sensors

$j = 1,2,3,.., m$ modes (discriminants)

As an example, let there be one sensor, (n = 1), operating in two modes, (m = 2). The sensor might be a radar operating in the Ground Moving Target Indicator (GMTI) mode, (j = 1), and the target reflectance mode, (j = 2). Given the appropriate time and spatial conditions, the probability of detection by the radar, P_D, in at least one of its modes is given by

$$P_D = 1 - (1-P_{11})(1-P_{12})$$

The following array shows the resulting P_D for three representative cases of P_{ij}.

CASE	P_{11}	P_{12}	P_D
1	0	.7	.7
2	.6	.7	.88
3	0	0	0

Case 1 might represent the situation where the target is stationary and hence the probability of detection in the GMTI mode is zero. Case 2 represents the situation where both modes are operative and demonstrates a monotonic and asymptotic increase in the probability of detection as the number of applicable sensor modes is increased. Case 3 illustrates the situation where there is either a sensor failure or conditions exist such that all $P_{ij} = 0$. This seemingly trivial case substantiates the intuitive feeling that depending on only one sensor to accomplish a given function has serious implications on mission reliability.

Now in this same example, consider the addition of two more sensors, such as a FLIR operating in the thermal emission contrast mode, and a CO_2 laser radar operating in the GMTI and target reflectance modes. Table 3 depicts the sensor/mode relationships and provides a set of representative P_{ij}.

		SENSOR		
		RADAR	FLIR	CO_2 LASER
MODES	j \ i	1	2	3
Ground Moving Target Indication	1	0.6	0	0.5
Target Reflectance	2	0.7	0	0.4
Thermal Contrast	3	0	0.8	0

TABLE 3. SENSOR/MODE RELATIONSHIPS

Using these probabilities, the probability of detecting a target by at least one sensor in one mode is given by

$$P_D = 1 - (1-P_{11})(1-P_{12})(1-P_{23})(1-P_{31})(1-P_{32})$$

and

$$P_D = 1 - (1-.6)(1-.7)(1-.8)(1-.5)(1-.4) = .9928$$

The addition of two more sensors has substantially increased the probability of detection (still monotonic and asymptotic), and has added the feature of "graceful degradation." If one or two of the sensors fail, the resulting P_D is never less than that of the remaining operative sensor(s). Thus the probability of successful function accomplishment using multisensor/multimode arrangements can be maintained relatively high by choosing sensors and modes such that the catastrophic condition of all $P_{ij} = 0$ simultaneously is an event with extremely low probability.

This relatively simple approach and example allows us to examine the difficulties of answering the questions of how many and which kinds of sensors to select. Since more sensors and modes provide increasing probabilities of successful function accomplishment, how many are enough? The asymptotic behavior of the increase suggests selecting a point of "diminishing returns", beyond which the increase in P_s does not warrant the resulting system cost, complexity, weight, etc. Given that such a point is selected (e.g., $P_s = 0.9$), the numbers of sensors and modes required to achieve it depend upon the values of the P_{ij}. The values of the P_{ij}, in addition to being sensitive to hardware failures, are dynamic functions of weather and battlefield conditions. Sensor data will appear, fade, and reappear as sensors are affected by various obscurants and countermeasures. The complex and varied impacts of these conditions make the selection of sensors and modes an extremely difficult task. Compounding the problem, is the question of operator involvement. The values of P_{ij} are ultimately determined when an actual target detection or classification declaration is made. If this final declaration must be made by the human operator, the number of sensors will be limited by the operator's ability and time-line constraints. As the final recognition process becomes more and more automated, however, the number of sensors can be increased and the operator can be relegated to the role of system monitor with the option to participate in a mode of management by exception. Fortunately, the development of automatic target recognition algorithms for FLIR and CO_2 laser radar imagery show a great deal of promise and suggests that the operator will not be the limiting factor in the number of sensors to be selected.

Sensor selection is also complicated by the fact that target recognition is a significantly different task than determining parameters such as altitude, airspeed, heading, etc. Whereas these parameters are normally obtained with a high degree of <u>accuracy</u> from direct, or minimally processed sensor outputs, target detection and classification are usually achieved with a high degree of <u>probability</u> only after substantial amounts of data and image processing. The requirement to accomplish this signal processing in very near real-time can have a substantial impact on how many and what kinds of sensors are selected, and how they are integrated.

3. SENSOR INTEGRATION

The level of performance of a multisensor/multimode system is a direct function of the degree of integration achieved. To reach desired levels of probabilities of function accomplishment and at the same time reduce operator workload and weapon delivery timelines, will probably require the development of a process referred to as "information fusion." This concept is based on the premise that the probability of successful accomplishment of a given function by at least one sensor can be considerably enhanced by correlating the outputs of several information sources. For example, by correlating a prospective target declaration from a shape recognition algorithm operating on FLIR imagery with the reflectance output of a radar, the probability of false alarm due to nonreflective decoys can be reduced. Doppler vibration signatures, derived as outputs from a CO_2 laser radar, can be correlated with shape recognition algorithms operating on FLIR and CO_2 laser radar imagery to help classify tracked versus wheeled vehicles. The detection or classification of a target using "targeting" sensors can be further aided and substantiated by correlating information obtained from other sources, such as the radar warning receiver or a data link, such as the Joint Tactical Information Distribution System. Although many system architectures have been proposed, the physical realization of information fusion for the targeting task rests on the development of viable sensor monitoring, cueing, and correlation techniques.

Devices to monitor and make pertinent sensor measurements, as well as sensor self-test, have been demonstrated, but near real-time automatic selection of the best of several sensor outputs in an integrated system has not been shown. Sensor cueing has been successfully mechanized in many multisensor systems, but the function of scene and target registration necessary to correlate simultaneous target data from more than one sensor has not been perfected. Numerous approaches to multisensor information fusion (algorithms and decision logic) have been postulated; however more detailed analysis and simulation are necessary to validate the concepts. Finally, although there have been demonstrations of automatic target recognition using FLIR, MMW, and CO_2 laser radar data, the process is relatively immature and will require significantly more data gathering, development, and validation before it can be reliably used in accomplishing the air-to-surface mission.

The process of making appropriate sensor selections and developing the required monitoring, cueing, and integration techniques would not be complete without a means of evaluating the performance of the resulting multisensor/multimode systems against what is currently available.

4. SYSTEM EVALUATION

The development of sophisticated digital computer simulations provides a relatively quick and inexpensive means of gaining insight into the value of various multisensor/multimode options. In a number of studies conducted for the Avionics Laboratory, analyses of multisensor/multimode system performance in various obscurant and countermeasure conditions were conducted, and an overall system evaluation was undertaken. Several multisensor/multimode options were synthesized and evaluated against each other and against a baseline system, an F-16 aircraft with the APG-66 multimode radar and an Imaging Infrared Maverick display as the only targeting aids. Candidate targeting sensors and modes considered in the studies are shown in *Table 4*. *TV was not seriously considered because of its marginal* utility in degraded weather and night operations.

SENSOR	MODES
X or K_u Band Radar	Real Beam Ground Map Synthetic Aperture (10' resolution) Ground Moving Target Indication/Track
MMW Radar 80 - 100 Gh	Ground Moving Target Indication/Track Doppler Vibration Signature
CO_2 Laser Radar 10.6 μm	Ground Moving Target Indication/Track Doppler Vibration Signature Target Reflectance Target Shape Recognition
FLIR 3 - 5 μm 8 - 12 μm	Target Shape Recognition Thermal Contrast Detection

TABLE 4. CANDIDATE TARGETING SENSORS

The postulated scenario was a conventional conflict of relatively high intensity between NATO and Warsaw Pact forces. Interdiction missions against armored target columns at various distances behind the forward edge of the battle area were examined. Threat defenses were specified and appropriately considered during the low altitude (∿200 ft) ingress and egress and during pop-up maneuvers in the target area. Countermeasures and varying weather conditions were also introduced. Various assumptions were made about probabilities of detection and classification by individual sensors as well as by the human operator. Automatic capabilities to perform sensor monitoring, cueing, and correlation were also assumed.

The overall results of the evaluations indicate a potential improvement ranging from 1.5 to 3.3 in the number of tank targets killed at given probabilities of survival. The variability in improvement is due to the intricate relationships between sensors, aircraft maneuvers, weapon requirements, threat types and densities, countermeasures, and weather conditions. Although sensor selection rules and logic varied, it was generally concluded that the highest number of expected kills, for any given level of survivability, was achieved with three sensors: Radar, FLIR, and CO_2 laser. Radar was used primarily for early target detection in either the reflectance (ground map) or Ground Moving Target Indicator modes. FLIR and CO_2 sensors provided inputs to the shape recognition and target classification logic. The CO_2 laser and MMW radar inputs were used in doppler vibration automatic target recognition modes. The radar and CO_2 systems were also used for target location and tracking, and terrain following/obstacle avoidance during ingress and egress.

The evaluations specifically highlighted the value of the multisensor/multimode approach in the presence of countermeasures. Most targets of interest have multiple discriminants or signatures which are extremely difficult for the enemy to reduce simultaneously. Typically, as one target signature is reduced, another is enhanced. Thus the problem of viably reducing or masking all target signatures simultaneously, or simultaneously denying both electro-optical and radio frequency sensor operation is considerably complicated by the use of multiple sensors and modes.

One of the most significant results of the evaluations was a quantification of the increased firing opportunities against multiple targets during a single pass over the target area. In one interdiction simulation, it was shown that a fully automated Radar/FLIR/CO_2 laser multisensor system using Imaging Infrared Maverick missiles would be expected to kill 2.5 more targets than the baseline F-16 system. The simulation also showed that manual operation and human assimilation of the multisensor data outputs was half or less as effective as the automated system.

5. CONCLUSIONS/PROGNOSIS

Analyses and simulations of various multisensor/multimode options for air-to-surface missions indicate the potential for significantly reduced operator workload, increased mission effectiveness, especially in an adverse weather and countermeasure environment, and increased survivability. These improvements result from the systematic and synergistic integration of various sensors and modes, with emphasis on automatic target recognition and information fusion. The translation of these improvements from simulation results based on a multiplicity of assumptions to performance results based on hardware and software validation is a formidable challenge; however, the prognosis for success is quite favorable.

The multisensor/multimode approach to the air-to-surface mission is already being pursued by the modification of existing weapon systems. The addition of PAVE TACK to the F-4 and F-111, the Low Altitude Navigation, Targeting, Infrared for Night (LANTIRN) system for the F-16 and A-10, and multiple electro-optical sensors for the B-52 are but a few examples. System designers of future aircraft must look beyond the constraints imposed by retrofit considerations if the full potential of the multisensor/multimode approach is to be achieved. There are numerous challenges spread across many technical disciplines; however, the technologies to meet these challenges can be matured within the next 3 - 5 years, if a coherent development strategy is formulated and pursued.

A concerted effort is needed to define an acceptable set of sensor (FLIR, MMW, CO_2 laser) parameters against which large quantities of multisensor target signature data can be collected. Data collected under many and varied weather, background, obscurant, and countermeasure conditions are fundamental to the success of development and validation of automatic target recognition algorithms and multisensor correlation techniques. These algorithms and techniques are the essence of the automated multisensor/multimode system, and must be validated to a very high degree of confidence across a wide spectrum of operating conditions. Sensor designs must include the requirements for, and interface with, automated data processors, and strive for physical integration which uses common apertures and internal installations. Functional integration should preserve and capitalize on the graceful degradation possibilities inherent in the multisensor approach and information fusion exploited to the maximum practical extent.

With the technology challenges met and the multisensor/multimode system performance proven by man-in-the-loop simulations and system demonstrations, weapon system planners can perform the cost effectiveness studies and trades which will inevitably shape the final designs of multisensor/multimode systems of the future.

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14. Abstract

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